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Part I.]

PAPERS

UPON THE

SUPPLY OF WATER TO TOWNS.

BY

BALDWIN LATHAM, C.E., A.I.C.E.,

Member of the Council of the Society of Engineers.

LONDON:
E. & F. N. SPON, 16, BUCKLERSBURY.

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INTRODUCTION.

IF we look to man as the lonely inhabitant of the plain, or find him congregated with his fellow-men in our cities or towns; or to the beasts, birds, or reptiles that roam the wilds of nature unfettered and unrestrained; or to the majestic tree that rears its lofty head in the primeval forest; or the tiny floweret that we tread beneath our feet; or direct our attention still closer to a world of beings so minute, that, aided by the most powerful microscopes, many of them are only distinguishable by that quivering movement which indicates the presence of life, we find that they are all mutually dependent for life and existence upon water; not only are the animal and vegetable kingdoms so dependent on it for existence, but it also enters so largely into combination with the mineral matters composing the crust of the earth, that in its absence the fabric of this world would collapse and all nature become an arid waste. A subject of so much vital importance as water supply, especially to the human race, is deserving of careful consideration; as its influences, from a sanitary point of view, are attended with immense results for good or evil. The subject of water supply is one which has more or less occupied the attention of men of all ages, and in an historical point of view is well worthy of consideration, especially as with all the boasted advancement of the present age it is a question if our modern works for supplying water surpass those of ancient Judea, Greece, Rome, Mexico, and other places; indeed, all history goes to prove that wherever man had arrived at any considerable degree of civilisation, the subject of water supply had a share of his solicitude. The volume of sacred writ contains records of many works of this character, and the works of Vitruvius not only urge upon us the necessity that exists for the supply of pure water, but point out the modes in which it may be procured and purified. So impressed were our progenitors with the importance of a good and abundant supply of water, that they were always careful to settle in those localities where it could be the most easily procured. In the course of events, it may have been that the original settlement increased in numbers, and extended itself to such a degree, as to have affected the quality or rendered the quantity of water insufficient for the demand, when, from necessity, more distant sources of supply have been laid under tribute to furnish what has been required. This has been the case with many of the towns of this and other countries. It was the case with ancient Rome and many of the cities of the East.

In these papers it is purposed to inquire into the various methods that have been, and that are still, adopted, to furnish supplies of water to large cities or towns, and as all supplies are furnished by the rainfall, this part of the subject will be first treated of, and following it, the various sources of supply will be dealt with in order as they are more immediately connected with it.

Rainfall.

All supplies of water being derived from the rainfall, this subject should receive careful attention, as the sufficiency and constancy of all works for the supply of water are dependent upon it. There are, however, circumstances connected with each mode of procuring a supply that in some measure may modify or alter the quantity, or affect the quality, of the rainfall of every district; yet there is no source, however remote it may appear from the rainfall, that is not directly or indirectly affected by the amount of that rainfall.

Rain is the result of the condensation of aqueous vapour, which is, at all temperatures, more or less suspended in the atmosphere. The quantity of aqueous vapour capable of being suspended in the atmosphere increases in a greater ratio than the temperature, and the phenomenon of rain occurs when the air, saturated with moisture, loses its temperature, and precipitates the excess it is no longer capable of containing in an aëriform state, either in the form of dew, rain, hail, or snow. It is found that the first causes of rain are identical with those that produce the winds and currents in the atmosphere—viz. the changes of temperature, to some extent the electrical state of the atmosphere, and the magnetic state of the earth; consequently it very naturally follows that the winds have a very close connexion with the rainfall. Thus, winds blowing from a warm climate over a great expanse of sea would be completely saturated with vapour, which, upon coming into a cooler climate, would be precipitated; on the other hand, a wind blowing from the frozen regions of the Arctic ocean, and deriving its moisture from the ice and snow of those severe regions, would, when it arrived in a warmer climate, by lowering the temperature of the atmosphere of that climate, diminish its power to retain aqueous vapours; and if, at the time, it was surcharged with moisture, a fall of rain must ensue. The physical conditions of every locality have some effect upon the rainfall. Thus, from observation, it has been ascertained that the rainfall is greater in mountainous districts than in level countries, which is probably owing to currents of air saturated with vapóur striking against the mountain-sides, and losing temperature by contact or by reason of being compelled to ascend into higher and colder regions; there is, however, a limit to the effects produced by elevation, for there are regions too high to experience any heavy rainfall, for the rains of Switzerland and the Alpine regions are not greater than those in the north of this country. The amount of rainfall is considerably influenced by the position of the locality with respect to the currents in the atmosphere: for example, it is found that the prevailing winds in this country are westerly, and come to us from a warmer climate; after sweeping over the face of the great Atlantic ocean they are naturally saturated with moisture, and, striking the ridges and high lands on our westerly coast, discharge the greater portion of their burden there. Thus we find it is nothing uncommon in the counties of Cumberland, Westmoreland, and Lancashire, to have an annual depth of rainfall equal to 6 ft., while in Cambridgeshire, on the eastern side of the country, the annual rainfall seldom exceeds 22 in. The rainfall also varies with the seasons of the year, the rainfalls of this country being greater in winter than in summer, because the temperature of the atmosphere is decreasing in winter, and with it its capacity for retaining vapour, while in summer the opposite is the result. But it will also be found, as a rule, that heavier rains fall in summer than in winter, although there may be fewer showers; because in summer the atmosphere has greater powers for retaining moisture, so that when the causes that induce a fall of rain are brought into action, there is a larger amount of moisture to be precipitated. In Germany the rainfalls of winter and summer are about equal; at St. Petersburg the rainfall of winter is but little more than one-third the rainfall of summer;

while in Siberia the rainfall of winter is but one-fourth that of summer.

The rainfall of a district is ascertained by an instrument termed a rain gauge; and in fixing these gauges it should be borne in mind that the position and construction of the gauge has much to do with the value and accuracy of the results recorded; thus the fact has been well established that the amount of rain collected diminishes as the gauge is removed from the ground. Various reasons have been ascribed for this phenomenon. The most likely are that the cold rain drops condense more vapour in their descent, and carry it down with them; or, as has been supposed by Mr. Baxendale, of Manchester, that vapour that has lost its caloric of elasticity is capable of being suspended in the atmosphere in an invisible state, and is collected by the falling drops of rain. Rain gauges are of various forms, but those which have floats and graduated rods, that rise with the rainfall, are objectionable if the rod is exposed, as they are likely to exaggerate the rainfall of any district, because the rod collects rain driving in an angular direction.

In the tumbler gauge a portion of the rainfall might be lost, as a certain amount was necessary to overcome the friction of the machine, and if anything less than that amount fell, it might be evaporated without being recorded. Again, in all gauges there was more or less a loss produced by the adhesion of the water to the surface that first received it; and that portion did not enter the measuring chambers, but was evaporated.

The effect of those errors, when considering the abundance of a supply of water, was rather beneficial than otherwise; but when considering the construction and stability of the works themselves, it would be well to allow for rather greater floods than the rain-gauge would record. The form of rain-gauge had much to do with the accuracy of the results: thus, a rain gauge having a rim inclined inwards, at an angle of 45 deg., was objectionable, as, when the rain was driving at an angle less than a right angle, a certain amount would be thrown into the gauge, and therefore the results would be exaggerated; a gauge having the rim inclined outwards was liable to contrary errors. He believed that a gauge with a pretty deep rim nearly perpendicular was by far the best form; such a gauge would retain in the funnel three or four inches of snow. The applicability of a rain gauge to record correctly in winter, should receive some attention, as many gauges in use were unable to retain anything approaching the quantity of snow falling at the time of a heavy snowstorm. In fixing rain gauges, care should be taken that they were not shaded by trees, buildings, or other things, and that the rim of the gauge was perfectly horizontal.

The infiltration gauge consisted of cylinders of cast-iron filled with earth and chalk. There could not be the slightest doubt but that gauges of that description were liable to very great errors, owing to the inability to construct a gauge that would correctly represent and perform all the functions of the natural surface of the earth; consequently, the materials in artificial gauges were found in course of time to become concreted more or less, and resist the passage of water.

The amount of rainfall recorded by the gauge cannot all be made available by the engineer in his works, as there are causes in active operation which render it impossible to collect the entire rainfall of any district. Therefore the engineer has to deal with resultants that arise during the constant and incessant circulation of water, and before he can arrive at correct results he must carefully consider the subjects that affect the rainfall.

RAINFALL TABLES.

Name of place.	Altitude above sea level.	No. of years' observation.	Minimum rainfall.	Maximum rainfall.	Average rainfall.
	Feet.		Inches.	Inches.	Inches.
Aberdeen	115	6	27.07	43.78	32.55
Allenheads, Westmoreland	1300	7	38.3	58.5	47.9
Applegarth, Dumfries	...	12	24.0	44.1	33.8
Arbroath	75	5	23.69	30.5	27.23
Ashton, Leicestershire	...	...	...	...	40.0
Aylesbury, Bucks	...	3	22.5	34.7	28.4
Bacup	...	...	...	...	40.0
Balfour	130	4	24.38	27.82	25.94
Barry	35	5	23.78	38.16	28.73
Bath, Somerset	...	3	...	37.8	32.4
Bedford	100	9	17.9	32.3	22.3
Belfast	...	...	32.0	40.0	36.0
Birmingham	380	6	19.9	29.2	25.5
Bolton, Lancashire	320	10	42.2	58.6	49.5
Boston, Lincolnshire	30	25	16.1	28.8	23.1
Bowhill	653	4	25.35	35.23	26.34
Breock, St., Cornwall	...	13	32.0	51.9	41.0
Braemar	1110	6	27.97	40.06	33.99
Bressay	25	4	31.44	50.3	37.68
Bury, Lancashire	300	13	28.6	50.6	41.7
Caermarthen	...	...	...	...	42.0
Caleton Mor	65	5	37.3	49.37	44.46
Carlisle	...	24	25.68	35.84	30.57
Chapel-en-le-Frith, Derby	1121	8	33.0	52.3	43.0
Chatsworth	...	16	...	...	27.66
Chiswick, Sussex	25	25	15.2	29.7	24.0
Chorley, Lancashire	...	...	...	...	48.0
Clifton, Somersetshire	228	10	22.6	39.5	31.02
Cobham Lodge, Surrey	80	25	16.8	31.7	24.5
Cockermouth	...	3	34.9	55.4	45.4
Croydon, Surrey	...	11	16.26	33.8	25.33
Denton West, Westmoreland	276	5	29.85	40.36	36.4
Dewsbury	...	...	...	...	45.0
Dickleborough, Norfolk	120	10	18.4	32.4	25.0
Douglas, Isle of Man	103	7	24.5	37.9	30.3
Drumlanrig	186	5	39.95	50.33	46.79
Dublin	...	...	...	...	45.0
Dukinfield	...	...	...	...	36.0
Dumfries	...	16	...	...	52.0
Dundee	100	7	...	...	33.0
Dunfermline, N.W.	230	7	22.45	42.80	35.28

RAINFALL TABLES—*continued.*

Name of place.	Altitude above sea level.	No. of years' observation.	Minimum rainfall.	Maximum rainfall.	Average rainfall.
	Feet.		Inches.	Inches.	Inches.
Easdale	25	3	48.4	60.4	54.83
Edinburgh	300	21	15.27	32.59	25.6
Elgin	28	5	23.92	29.36	26.6
Ely	140	6	20.0	34.30	25.13
Epping, Essex	...	10	22.5	32.2	26.6
Exeter, Devon	141	25	24.0	39.2	29.2
Fairfield, Lancashire	320	8	24.8	40.7	31.5
Fassaroc, Wicklow	200	8	24.7	57.5	36.8
Falmouth	120	9	31.7	50.1	40.1
Felthorp, Norfolk	...	5	20.0	25.8	22.6
Fethicairn	241	5	23.31	41.43	28.95
Gatesgarth, Westmoreland	326	3	...	...	117.2
Gilmonton, Lanark	600	5	35.3	60.3	47.7
Glasgow	200	6	33.5	46.2	37.43
„ Waterworks	...	...	...	...	60.0
Glencore, Rutland Hills	734	19	23.5	45.9	36.11
Goodamoor, Devon	600	16	41.6	70.1	56.8
Gosport, Hants	30	7	24.0	34.3	30.2
Grasmere, Westmoreland	180	3	...	...	107.5
Great Gable, do.	2925	2	...	...	89.4
Greenock	64	5	50.5	68.5	60.0
Greenwich Observatory	143	12	16.4	33.2	23.93
Guernsey	123	9	25.6	49.1	36.3
Hastings	...	12	22.36	43.53	31.98
Hawarden	260	9	20.3	40.4	27.2
Honiton, Devon	...	5	25.5	41.7	33.2
Huddersfield	...	...	...	...	33.0
Hungerford, Berkshire	320	12	19.28	34.07	26.58
Hyde, Lancashire	320	10	30.6	39.6	35.2
Kendal	...	25	...	...	53.944
Kettins	228	5	31.09	38.17	33.71
Keswick, Westmoreland	258	3	47.0	74.3	60.1
Kilmarnock	...	...	...	...	33.0
Kingston-upon-Hull	...	...	28.0	30.0	...
Lampeter	420	5	36.7	55.5	43.2
Lancaster	...	20	...	...	39.71
Leek	...	...	...	...	45.0
Leicester	...	...	...	...	24.0
Lincoln	...	...	...	...	24.0
Linton, East	90	5	23.32	34.95	27.65
Liverpool	37	23	22.2	49.5	34.7
London	...	40	...	...	25.3
Macclesfield	...	...	...	...	40.0
Manchester	...	33	25.0	45.1	36.14
Millfield, near Stirling	169	4	32.1	44.74	36.81
Milne Garden	100	...	25.8	32.8	29.94
Moss Loch, near Rochdale	500	11	25.9	37.7	30.3

RAINFALL TABLES—*continued.*

Name of place.	Altitude above sea level.	No. of years' observation.	Minimum rainfall.	Maximum rainfall.	Average rainfall.
	Feet.		Inches.	Inches.	Inches.
Newcastle-on-Tyne	121	2	...	...	89.4
Norwich	39	11	20.3	33.2	26.5
Nottingham	203	15	17.4	38.5	26.65
Oldham	...	...	...	...	35.0
Ormskirk	...	...	29.0	40.0	...
Oxford	210	11	17.7	40.4	27.2
Paisley	...	...	...	...	51.33
Pencarrow, Cornwall	...	3	37.9	57.3	45.3
Penzance	40	9	34.7	53.9	43.1
Perth	66	5	30.50	38.36	33.53
Plymouth	30	10	27.9	45.4	35.7
Preston	...	...	...	...	43.0
Reading, Berks	...	17	21.2	32.8	25.4
Rochdale	500	16	34.4	61.1	46.7
Rugby	...	...	...	...	22.0
Rusholme, Lancashire	...	...	30.0	40.0	35.0
Sandwich	100	5	27.41	44.51	36.33
Scomie	26	4	39.4	42.87	41.11
Seathwaite, Westmoreland	...	3	...	...	140.6
Shipley	...	...	...	...	30.0
Southampton	60	...	28.9	48.7	...
Sowerby Bridge, York	300	11	26.5	30.8	27.2
Sparkling Tarn, Westmoreland	1900	2	...	...	124.0
Stobo Castle	600	4	16.86	25.6	21.78
Stonyhurst	381	9	37.6	59.3	45.2
Storroway	70	5	35.69	45.84	41.62
Styehead, Westmoreland	1290	2	...	...	92.8
Swaffham Bulbeck, Camb.	...	7	19.6	29.7	23.8
Swansea	...	...	...	...	36.0
Stractine	200	6	29.72	38.16	32.88
Stubbins, York	...	11	26.1	40.2	32.3
Thirlstane	558	5	23.68	28.86	27.35
Thurston	320	5	23.90	37.16	29.21
Tongue	40	4	30.3	46.7	40.96
Torquay	120	7	19.4	50.2	29.2
Tottenham	50	7	19.3	29.1	24.8
Tyndum	792	3	...	...	74.2
Wellington	160	20	17.8	33.3	24.9
Whitehaven	90	3	35.0	52.0	47.0
Wigan	...	...	...	...	40.0
Wrexham	...	...	...	...	38.0
Yester	420	5	29.73	42.35	34.5
York	50	9	18.5	29.4	23.4

CIRCULATION OF WATER.

The first source of rainfall is the ocean; by evaporation a portion of its waters are raised into the atmosphere to be again precipitated in the form of rain; of this a portion is again evaporated—another portion absorbed, while another portion may find its way back to the ocean—its original source. Thus it is that "the circulation of water is incessant—now in the ocean, now in the atmosphere, now in the tissue of plants or animals, now in the crust of the earth, now coursing its surface; and anon in the ocean again, to repeat the same circuit, and this without interruption while the present relations of the universe endure. In general this circulation is slow and gradual—so slow, that the spherule of vapour now rising from the ocean may be years, or even ages, in returning to its native source. Disseminated in the tissues of plants, or locked up in the crystallisation of minerals, its cycle seems interminably arrested, and yet we know that decay and degradation will some day or other bring about its liberation. On certain occasions, however, and in certain localities, its circulation is so rapid that you absolutely perceive the hazy vapour ascending from the sea, rolling landward in mist and cloud; coming in contact with cold mountain-peaks, condensing into rain, and falling in torrents to augment the runnels and runlets. From runnel to stream, from stream to river, the mass swells, and hurries downward and onward to the great receptacle whence the light and filmy vapour originally arose, there to resume the same career, and perform analogous functions." The water evaporated from the ocean may, for all practical purposes, be said to be perfectly pure; but in the course of its circulation it is constantly contracting impurities, and as frequently undergoing processes of purification. In this mighty circulation it performs important functions in re-arranging not only the tissues of plants and of animals, but in absolutely re-arranging the strata of the earth. All matter is animated in its presence, and it is, as it were, the life-blood of all creation. It is during the progress of this incessant circulation, as has been before observed, that the engineer has to deal with it, and in doing so he will find the available rainfall dependent upon certain conditions, such as the nature of the soil, the declivity of the district, and the rate of evaporation. If the nature of the surface receiving the rainfall is naturally, or has been made artificially impervious, there will not be any absorption, and evaporation will be the chief cause for any diminution of the quantity.

EVAPORATION.

It is extremely difficult to arrive at correct results as to the amount of evaporation taking place at any time either from land or water, as there are so many circumstances and conditions that may affect the subject and lead to errors: considerable caution must, therefore, be exercised in dealing with the results, and it is always better to be on the safe side, that the calculations of the engineer may not lead to a diminished supply of water. It is quite clear that the rate of evaporation from land is very much less than the rainfall, otherwise we should have no rivers or springs. But the rate of evaporation from water surfaces considerably exceeds that from land, and in some cases the rainfall. Dr. Dalton found, by experiment, that the mean daily quantity evaporated from a vessel of water freely exposed to wind and sun, was, in March, .033 in.; in April, .055 in.; in May, .075 in.; in June, .063 in.; in July, .122 in.; and in the hottest weather of summer he never found the rate of evaporation to exceed .200 in. per day. Experiments made by Mr. Luke Howard, at Plaistow, on the rate of evaporation from water surfaces gave .912 of the rainfall as the amount evaporated. In similar experiments made by M. Valles, at Dijon, the rate of evaporation was ·966 of the rainfall. A like experiment, made at the same time, but from a smaller vessel, gave a greater amount of evaporation, which in this instance exceeded the rainfall of the period. It is probable that the mean rate of evaporation in this country from water surfaces may equal 36 in. or 37 in. In other countries the rate will increase considerably with the mean temperature.

The rate of evaporation from land surfaces must be, as has been before observed, much less than the rainfall; but the precise rate it is difficult to arrive at, as the character of the soil, the state of its cultivation, and its general contour, affect the results very much. Thus, if the land is uncultivated and exposed, it would, by the action of the sun and wind, be dried very quickly; and when once the surface is dried, the rate of evaporation falls off; but in the cases where verdure covers the surface, whether it be in the nature of woods, or of grassy meadows, the vegetation protects the surface of the earth from the direct action of the sun and wind; yet in a more regular way evaporation is progressing, as the roots of trees and plants are abstracting the moisture from the soil, and retaining but a small portion, they give off the remainder into the atmosphere in the form of vapour. Experiments made by Bishop Watson on evaporation, on a bright and hot sunny day when there had been no rain for a month, give the rate of evaporation from grass as .035 in. in twelve hours. A similar experiment made after a thunderstorm gave .087 in. From an experiment made by Mr. Lawes a plant of wheat was found to exhale 100,000 grains of water in 172 days, or the period of growth: which would be at the rate of 2200 gallons of water evaporated from an acre of ground per diem, representing a rainfall of .36.5. It is probable, however, this is rather a high estimate.

The effect of evaporation, either from land or vegetation, is also a check upon itself, for as the circumstances arise to create a fierce rate of evaporation, they are in some measure counterbalanced by the cooling effect evaporation has upon the surface from which it takes place. The circumstances that favour evaporation are heat, a dry atmosphere and a low barometrical pressure or decreased weight of the atmosphere upon the evaporating surface; winds or currents of air also greatly promote evaporation, for they not only bring the air into closer contact with the water, but remove the particles of moisture as they are converted into vapour, and are continually bringing a fresh volume of air into action to receive its load of vapour. The rate of evaporation from most surfaces is in some measure compensated for by the deposition of dew, which is very rarely estimated with the rainfall.

ABSORPTION.

The amount of rain capable of being absorbed by the surface upon which it falls depends, in a great measure, upon the temperature, the geological formation, and physical outline of the district. In making calculations as to the amount absorbed, we must bear in mind that the area of the surface is the only constant quantity we have to deal with, as its condition and capability for absorbing water vary considerably with the seasons of the year. Under such varying conditions the amount of water absorbed, and capable afterwards of being used, when issuing from springs, or by sinking wells, is extremely capricious. The greater the quantity of water evaporated or retained by vegetation, the less will remain to be absorbed. Rain descending upon a dry and parched surface in the heat of summer, or during the occurrence of drying winds, will be nearly all evaporated, so that the rate and amount of absorption depend materially upon the absorbent properties of the soil. Thus in the sands of the red sandstone formation the rainfall is absorbed as fast as it touches the surface, and the same may be said of the rain falling in many places on the chalk formation, while upon the clay soils, or impervious formation, the greatest part of the rain would generally be directly conveyed away by surface streams. The contour of a country, in a measure, affects the rate of absorption, as the rainfall on mountains or hilly districts has a greater tendency to gravitate rapidly to the rivers, while on table-lands the water lingers, and consequently such lands are favourable to absorption.

Experiments made by Dr. Dalton, extending over three years, on the new red sandstone formation, show that 25 per cent. of the whole rainfall percolated to a depth of 3 ft. Experiments made at Fernbridge, in Yorkshire, by Mr. Charnock, on the magnesian limestone formation, resulted in giving but 19.6 per cent. of rain percolating to a depth of 3 ft., and a like experiment made by Messrs. Dickenson and Evans, on the sandy gravelly loam which covers the chalk about Watford, gave as much as 30 per cent. of the rainfall percolating to a depth of 3 ft. In the latter experiment the average rainfall was found to be 26.33 in. per annum, and the average mean filtration 7.92 per annum. Of this quantity 7.34 in. were absorbed between October and March inclusive, which was at the rate of 55½ per cent. on the rainfall of that period, whilst between April and September inclusive only .58 in. of rainfall was absorbed, which was at the rate of 4½ per cent. of the rainfall of that period. From this experiment it appears that the largest amount of rainfall is absorbed during the months of November, December, and January, when, practically, all may be said to be absorbed; and that the least amount at any time absorbed was in the month of August, when, practically, it was nothing. It has been calculated by Mr. Beardmore, C.E., that of the rainfall absorbed in winter 60.7 per cent. is carried off directly at the time of the rainfall, leaving 39.3 per cent. to supply rivers and wells; and of this probably only 3¾ per cent. of the rainfall absorbed really goes to furnish a supply for wells, which in a measure will account for the failing of many ordinary wells in certain seasons of the year. This process of absorption plays a very important part in the economy of nature, as by it the rainfall is stored for the purposes of utilisation by both the vegetable and animal kingdoms. Were it not for this our rivers would only flow in times of rainfall, and at such times their impetuosity and floods would be so great as to prove a great drawback to their subservance for the purposes of man, and at other times their channels would be dry, which would probably be a greater disadvantage, as all vegetation would suffer materially, if it could survive the droughts we should experience; as it is, the water falling on the surface penetrates it to various depths, forming for itself subterraneous reservoirs, and it is from these reservoirs the water is emitted which keeps our rivers flowing and supplies water for vegetation, even in the time of the greatest drought.

MODES OF OBTAINING SUPPLIES OF WATER.

Having considered the two great causes that tend to diminish the amount of the rainfall that can be made available by the engineer in his works, it is now necessary to direct attention to the various expedients adopted for securing and furnishing supplies of water, and which may be classed under the following heads:—

1. By the interception of the rainfall before it reaches the ground, or before it has penetrated it; such, for example, as supplies taken from rain collected on the roofs of houses, or on the paved and impervious surface of our yards, courts, &c.
2. By the interception of the rainfall after it has reached the ground, but before it has run off by its natural course.
3. From rivers and streams.
4. From natural springs.
5. From wells.

RAINFALL COLLECTED FROM ROOFS, &c.

One of the simplest modes of securing a supply of water is by collecting and storing the rainfall that falls direct upon the roofs of our houses, or upon the paved surfaces of yards, &c. This mode is no doubt very ancient, and was probably one of the first expedients adopted for securing a supply wherever man had advanced to that state of civilisation as to require a house with an impervious covering for his shelter. The amount of surface available and suitable for receiving the rainfall is generally limited, so that the quantity of water capable of being stored is also limited; yet there are many places that depend upon this mode for procuring their principal supplies of water. A large portion of the supply of water for Jerusalem, Constantinople, and other ancient places, was procured by storing the rain water in underground cisterns, some of which are in use to the present day. The city of Venice is an example of one of many places supplied principally by rain water; but it is found that, in long, dry seasons, the inhabitants of such places as are dependent on this mode of procuring a supply of water are often put to great straits for a supply; and if we assume that 60 ft. of roof or other impervious surface is available for each individual of the population, with an annual rainfall of 30 in., if all of it were collected and stored, it would only give two and a half gallons per day as the quantity for each individual. Professor Leslie made a calculation, with respect to a lofty house in Paris, containing twenty-five persons, and he found that each person might procure a supply of a little over one gallon per day. When these quantities are compared with the twenty to fifty gallons per head per day at present used by populations having a constant supply of water, it is easy to see the disadvantages of depending entirely upon the rainfall collected on roofs and other surfaces connected with our dwellings as the sole mode of supply; at the same time it is advisable in many, if not in every house, to utilise the rainfall that can be procured on the site, as all such water, if collected and used, will have a good effect in diminishing the supplies it may be necessary to furnish by other and artificial means; moreover, such supplies of rain water are, in many districts, invaluable, where the water is naturally hard, and soft water for the toilet and some other purposes is an absolute requirement.

The quantity of rain water collected from the roofs of houses in cities or towns is invariably more or less varied in the degree of its purity; indeed, it has been determined that pure water can nowhere be met with in nature, and the purer the water the more likely it is to contract impurities. The impurities contained in rain water are contracted partly by absorbing gases from the atmosphere in its descent, and partly from the impurities it meets with upon the surface that receives it, such as dust, insects, and soot, which accumulate during dry weather; and these impurities, although affecting the quality of the water for some purposes very slightly, yet when they are allowed to accumulate in the cistern or storing reservoirs, undergo constant decomposition, and injure the quality of the water for many purposes. But inasmuch as many of these impurities, when first contracted, are of a mechanical character, they can be easily removed by a process of filtration, and as such system of purifying the rain water before it enters the cistern or tank is easily effected, it is very desirable that it should in all cases be done. In Venice this system has been adopted with great advantage and success, and Fig. 1, Plate 1, is a representation of the mode by which the water there is freed from its mechanical impurities; consisting of two wells concentrically placed. The inner well forms the pure water store, the outer receives the rainfall. In passing from the outer to the inner well the water has to filter through a stratum of sand. The best way to preserve the purity of rain water collected from the roofs of our dwellings is by preventing its exposure to light and heat; this can best be done in underground tanks, which should be well ventilated. It often happens that for the sake of convenience, tanks or cisterns are constructed and placed in the upper portion of our dwellings, so as to furnish a supply without having to use mechanical means to raise it; but the purity and freshness of the water can never be compared with that stored in underground receptacles. The size of a tank for storing the rainfall should be sufficient to give a supply during the longest periods of drought, and consequently will depend upon the amount of the rainfall, the area of the roof or other surface, and the quantity of water required. Provision should be made to store not less at least than 90 days' supply, otherwise the supply may fail during long periods of drought and when it is most needed. Mr. Bateman, C.E., has observed that droughts "vary in extreme length from, probably, 120 days on the west coast of the backbone of England to 240 on the east side."

WATER SUPPLIES TAKEN FROM COLLECTING AREAS.

The rain falling upon the surface of land, besides being partly evaporated and partly absorbed, has further a natural tendency to gravitate in the direction of the rivers and streams, which form the natural ducts or channels for carrying the rainfall back to the ocean, its original source. It is this portion, when on its way to the natural streams and water-courses, that is made use of in works of this character, and which are so constructed as to intercept the rainfall, either before it reaches its natural course, or, in some cases, after it has arrived in its natural channels, and to convey it to large impounding reservoirs, where it is stored in sufficient quantities for use as required.

Supplies taken from drainage, or collecting areas, or gathering grounds (as they are sometimes called), are by no means uncommon in this country, in conjunction with works for the supply of water to towns, and also for utilising the rainfall for mechanical purposes. Works of this description are not of modern origin, but have been in use in past ages in many countries. A portion of the water supply of ancient Jerusalem, as mentioned by Dr. Whitty and others, was furnished in this manner, as a large drainage area contributed to supply the Pools of Solomon with water—in fact, these pools are reservoirs formed like those of many modern works, partly by throwing an embankment across a valley, and partly by excavation. The contents of the three pools, as given by Dr. Robinson's measurement, are as follows:—First pool has a capacity of 1,634,475 cubic feet; second, 2,536,414 cubic feet; third, 3,873,937 cubic feet; making a total capacity of upwards of 50,000,000 of gallons. These pools are arranged in the incline of a valley, the smallest being the highest, and the largest the lowest pool. As the second pool is only 160 ft. from the first, and the lowest but 248 ft. from the second, it is quite clear that a much larger reservoir might have been made by carrying up the embankment of the lowest reservoir to a greater height; but the probability is, it was not done as a measure of safety, for the additional depth of water would have added immensely to the risk of damage; and, indeed, the extreme care and caution which seems to have marked all the early hydraulic works is by no means a bad example to follow. The gigantic reservoirs of Egypt, for storing the waters of the Nile for utilisation, are ancient examples of works of this nature, and are of so stupendous a character, and of so remote a date, as to perplex and confound historians, many of whom have classed them with natural formations. But, as Ewbank observes, all ancient writers unite in asserting that Lakes Nitocris and Mœris are the work of men's hands. China also contains many traces of the early development and high state of mechanical and hydraulic science; and vast reservoirs, for containing water for the supply of canals, for agricultural and commercial purposes, are not at all uncommon there.

The care and skill of the Romans is shown, amongst other works, in those of this character, for the supply of water to the cities and towns under their dominion; indeed, it is a remarkable fact that, in nearly every country and land subjugated by their arms, the remnants of their handiwork and skill are still to be seen. In many instances the benefits they conferred upon the past generations are still felt by the present generations occupying those countries. Works executed by them of the nature of collecting supplies from drainage areas are to be found in Spain, Egypt, and other places.

Like every other source of supply there are many circumstances to be considered in constructing works for procuring water from drainage areas, the principal of which are—the rainfall, character of the soil, natural configuration of the district, and the state of its cultivation. Having determined upon the amount of rainfall, which in all calculations for new works should be the minimum, we must next consider the various circumstances that tend to diminish it. We have already treated of these under the head of evaporation and absorption; but as each of these is more or less affected by the physical peculiarities of the district, we must carefully consider them. In every case where the surface soil is porous, a great portion of the rainfall will be absorbed; and in constructing works for collecting water from areas of this nature, it will be well to consider if, by suitable under drainage, a larger portion of the rainfall cannot be collected, which, under other circumstances, would sink deep into the ground, beyond the reach of works of this character. Again, it may sometimes happen that a porous soil overlies an impervious bed, when a large portion of the rainfall could be secured by under-drainage, or the formation of deep intercepting drains. Again, in places where the surface is quite or nearly impermeable, the formation of under drains will not add much to the quantity of water collected. It may then be taken by open channels, and the natural ones of the district will often suffice. Open channels are, however, objectionable, because, in most soils, the channel must be of such size as to limit the velocity of the current to a speed not exceding half a mile her hour; otherwise, the bed will be worn and the water made turbid. This necessarily slow motion is attended by its evils, as it favours the deposition of silt washed from the surface of the drainage area, and is also favourable to the development of vegetable and animal life, and loss by evaporation. Open channels also form receptacles for vegetable matter which the wind may carry in.

In considering the physical peculiarities of the district, it must be borne in mind that, if the district is level and not intercepted with valleys, the expense of making impounding reservoirs, which, in all works of this character, are absolute requirements, will add immensely to the cost of such work; whereas, in districts traversed by valleys—often containing natural streams—impounding reservoirs can be more cheaply constructed by throwing an embankment across the ravine, and at once forming a natural reservoir. In computing the quantity of the supply likely to be furnished by drainage areas, it is well not only to consider what may appear the natural areas or slopes receiving the rainfall, but also the geological areas, in considering which the engineer must pay particular attention to the dip and direction of the strike of the strata, as it materially influences the flow of water. For instance, it often happens that the supply may be augmented by springs, when the dip of the strata is in the direction of the slopes of the drainage areas; while, on the other hand, the supply may be diminished by the facility with which the water may be carried away by an absorbent strata, having a dip in a direction opposed to the slope of the drainage area, as illustrated in Figs. 2 and 3. The position, form, and dimensions of the drains for conveying the water to the reservoir will, in all cases, depend upon the contour of the district; but in cases where covered channels are used, the excavation, after receiving the conduit or pipes, is often filled up with broken stone, in order to facilitate the entrance of rain and drainage waters.

In laying out works of this character, attention must be paid to the area of land enclosed by the catch-water and other drains; and, when practicable, the main conduit, that will encircle the collecting area at the lowest point, should be arranged at sufficient elevation to procure a fall, so as to enable the water to be distributed, without mechanical means being required to raise it, to give sufficient pressure.

QUALITY OF WATER TAKEN FROM DRAINAGE AREAS.

In laying out works for the collection of water from drainage areas, it must be borne in mind that the nearer the actual rainfall water is collected the freer it will be from adventitious matter, and at the same time, in selecting drainage areas, it must be observed that purity of water and fertility of soil are never to be expected together. Water taken from drainage areas, where the substratum is peat, or from lands in a high state of cultivation, is objectionable; as in the former case many vegetable organic impurities will be present; while that taken from land in a high state of cultivation will contract and contain many organic and inorganic impurities. The best quality of water contributed by drainage areas will always be found in the barren districts of the primary geological formations, and in the moorlands on the sandstone rocks. Next to these, the water taken from pastoral districts will probably rank in purity, and that from cultivated districts will be the worst. In cases where the water is collected quickly from the drainage areas, and before it has had time to penetrate deep into the earth, it is comparatively pure; excepting in those cases of highly cultivated and manured districts. Water taken from some drainage areas supplied by covered drains will not be as chemically pure as water taken direct from the surface without being allowed to penetrate the strata; as when it penetrates the soil it may collect inorganic impurities.

QUANTITY OF WATER DERIVED FROM DRAINAGE AREAS.

Illustrated in Plate 1, Figs. 2, 3, and 4.

The quantity of water capable of being collected from a drainage area depends mainly upon the geological formation and physical outline of the district. If the district is of an impermeable geological character, having steep slopes, a very large portion of the rainfall can be collected; on the other hand, if the geological character of the district is porous, and its contour flat, as in some sandy and chalky districts, very little or no water could be depended upon from works of this character; and, as the geological character of a district approaches one or the other of these conditions, so will the per-centage of the rainfall capable of being collected fluctuate. The engineer, in constructing works deriving supplies from drainage areas, must take into consideration the amount of water capable of being yielded by springs flowing in the areas, as it may occur that the rain falling on a porous part of the district may make its appearance again at another point in the form of a natural spring. As has been already mentioned, if the surface of the drainage area is porous, resting on impervious strata, a much larger quantity can be obtained by under-drainage than if the water was taken from the surface only. The quantity of water capable of being taken by under-drainage, if the strata is uniform, will depend upon the depth of the drains. An experiment made by Mr. Milne, of Milne Garden, in Berwickshire, extending from June, 1848, to April, 1849, shows that under-drains 3 ft. deep, laid 15 ft. apart, gave nearly 36,000 gallons per acre; while drains laid 3½ ft. deep and 20 ft. apart, gave at the rate of 47,000 gallons per acre, which was about one-tenth the rainfall of the district. It is clear from this experiment that a considerable portion of the rain descending on the surface, either ran off at the time of the rainfall, and consequently did not penetrate to the depth of the drains, or it passed below them and out of reach of their action: in every porous soil a large portion of the rainfall could not be collected by drains placed a distance apart, as the water would penetrate deeper than the drains. From observations of some of the various works constructed for the supply of water from drainage areas, the amount of water taken and used varies from one-sixteenth to over two-thirds the rainfall of the district, as will be seen from the following examples of works in operation; but many of the works could probably supply a larger quantity, as the quantity given is the amount absolutely used. There can be no doubt that if the surface of every drainage area was, or could be made, impervious, and sufficient slope be given to it to carry off the water quickly, a very large per-centage of the rainfall might be used. But the great drawbacks to making the surface that should receive the rainfall impervious are—first, the expense; and, secondly, the restriction it would put on agricultural pursuits. The expense of making a surface impervious has been estimated by Mr. Hughes at 242*l.* per acre, which price would exceed the value of the water that would be collected from it, so that if this system had to be put in operation at the present prices paid for water, it would not pay. The sufficiency of the rainfall to furnish a supply of water may be derived from the fact that if two-thirds of the rainfall of England and Wales could be collected, it would furnish a supply to each individual of the population of a quantity exceeding 2500 gallons per day; but the rain falling on the sites of our cities and towns would not be sufficient for a supply according to the present rate of consumption. For example, the most crowded parts of London are peopled at the rate of one person to every 12½ yards; now, taking this area with a rainfall of 24.8 in., if two-thirds of it could be collected, it would furnish 2.63 gallons per head per day. In the

City of London one person has 40¼ yards area, which with the same rainfall and at the same rate would furnish 8.54 gallons per head per day. Although in a great place like London it would not be possible to utilise the quantity given, and the quality would not be the most desirous, yet for many purposes the quantity of rain falling upon the sites of our cities and towns, if utilised, would tend much to our advantage.

EXAMPLES OF WATERWORKS SUPPLIED FROM DRAINAGE AREAS.

Ashton, in Lancashire, is supplied from a collecting area of 378 acres on the millstone grit formation. The rainfall of the district is 40 in., and .384 of the rainfall is stored.

Belfast, in Ireland, is supplied from a drainage area of 980 acres. The supply is taken by open channels, and stored in reservoirs capable of containing ninety days' supply, at the rate of 102,000 gallons per day. With a rainfall of 32 in., .522 of it is used.

Bolton, in Lancashire, is supplied from a drainage area of 1041 acres, situated on the millstone grit formation. The supply is taken by covered channels, consisting of pipes laid in trenches, covered with gravel, and the trench then sodded over. The water is stored in a reservoir capable of containing ninety days' supply, at the rate of 2,000,000 gallons per day. The rainfall of the district is 50 in., and .619 in. of it is used.

Dublin New Works are supplied from the river Vartry, which has a drainage area of 14,000 acres, and with a rainfall of 45 in. and 20,000,000 gallons of water daily supplied. .500 of this will be used. The supply is stored in reservoirs capable of containing 120 days' supply.

Dukinfield, in Cheshire.—These works are constructed to be supplied partly from a drainage area of 383 acres, situated on the millstone grit formation, and partly by meter from the Manchester Waterworks. With a rainfall of 36 in., it is found that about one-half is stored and used. The water is taken from the land in both open and covered channels.

Glasgow is supplied with water from Loch Katrine, which has a drainage area of 43,000 acres, on the silurian formation, which supplies Glasgow with 23,000,000 gallons daily, besides 40,000,000 gallons daily, as compensation to millowners. 130 days' supply is stored; and with a rainfall of 60 in., .402 of it is used.

Greenock is supplied from a drainage area of 5043 acres. With a rainfall of 60 in., .603 of it has been observed to run off into the reservoirs.

Huddersfield, in West Yorkshire, is supplied from a drainage area of about 1000 acres, situated on the millstone grit formation. The supply is taken by covered channels, and 120 days' supply is stored, which, besides supplying 500,000 gallons of water per day to the town, gives a large quantity of water as compensation to millowners. With a rainfall of 33 in., .537 of it is stored and used.

Liverpool is partly supplied from wells, but principally from a drainage area of 10,400 acres, contributing to Rivington Pike. A supply of 120 days is stored, and with a rainfall of 55.5 in., .436 of it is stored.

Macclesfield, in Cheshire, is supplied from a drainage area of 2000 acres, situated in the coal measures. The supply is taken by covered channels, and stored in a reservoir capable of containing forty days' supply. With a rainfall of 40 in., .526 of it is used.

Manchester is supplied from a drainage area of 18,900 acres on the millstone grit formation, which furnishes a supply of 12,000,000 gallons per day, to a population of 550,000, and 55 cubic feet of water per second for twelve hours daily, as compensation to millowners. With a rainfall of 37 in., .617 of it is actually used, while from Mr. Bateman's evidence it appears that nearly three-fourths of the rainfall can be made available.

Oldham, in Lancashire, is supplied from a drainage area of 2700 acres, situated in the coal measures, which furnishes a daily supply to the town of 1,600,000 gallons, and 219 cubic feet of water per minute for twelve hours daily, as compensation to millowners. With a rainfall of 35 in., .415 of it is used, and six months' supply is stored.

Paisley is supplied from a drainage area of 790¼ acres, situated on the coal measures. The supply is taken by open channels, and 200 days' consumption is stored. From a recent report of W. R. Copeland, the engineer, it appears that during the last year, with a rainfall of 56.33 in., .548 of it was used; but the amount capable of being supplied he takes at 84 per cent. of the rainfall, as he allows but 16 per cent. for loss by evaporation and absorption.

Plymouth, in Devon, is supplied from a drainage area of 4000 acres, situated on the granite hills of Dartmoor. The supply is taken by open channels. With a rainfall of 44 in., .343 of it is used for town purposes.

Preston, in Lancashire, is supplied from a drainage area of 3000 acres, in Longridge Fells. The supply is taken both by open and covered channels, and 150 days' consumption is stored, with a rainfall of 43 in., but .232 of it is used.

St. Helen's Old Works are supplied from a drainage area of

280 acres, situated on the coal measures. The supply is taken by both open and covered drains, and is stored in a reservoir capable of holding 125 days' supply. With a rainfall of 30 in., .122 of it is stored and used.

Southampton is partly supplied from a drainage area of 120 acres, situated on the Eocene formation. With a rainfall of 23 in., one-third of it is collected.

Wigan, in Lancashire, is supplied from a drainage area of 2200 acres, situated on the coal measures, which furnishes a supply of 600,000 gallons per day to the town, and 800,000 gallons per day as compensation to millowners. The supply is taken by open channels, and 180 days' consumption is stored. With a rainfall of 40 in., .26 of it is used.

WATER SUPPLY TAKEN FROM RIVERS AND STREAMS.

The water taken from rivers and streams is supplied by drainage areas of large extent. The distinction to be drawn between works deriving supplies direct from drainage areas, and from rivers that receive their supplies from drainage areas, is this: In the case of drainage areas all the water of a particular district is dealt with, while in the case of rivers a proportion only of the water of a much larger district is taken. When all, or a large per-centage, of the water of a river or stream is required, such works may be classed with those taking supplies from drainage areas, and will require the storing reservoirs and appendages of that class of works, as is the case with the new Dublin waterworks. Generally the water of rivers consists of water falling upon the various geological strata, from some of which it flows off directly; while from others it flows after penetrating to various depths, and issuing in the form of springs; consequently, the quality of river water is subject to greater variation than that collected from a limited drainage area, and is, in fact, a sort of mean between the waters of many sources.

The flow from some rivers and streams is subject to great variation, as streams that take their rise in mountainous districts, or which run over impervious formations, are often subject to freshets, while at other times these channels may be nearly, or quite dry. It is found that the more impermeable the district, the more rapidly the streams swell and the rainfall is run off; whilst in permeable districts the soil retains the water and parts with it more slowly. Hence rivers flowing through such districts are not subject to such extreme variation of floods or droughts as those flowing through strata of a more impermeable character. The quantity of water flowing off by rivers and streams varies with the season of the year, and the physical and geological nature of the district from which the water is derived, or over which the river flows. The discharge of water from rivers is not always proportional to the watershed, but depends more especially upon the geological character of the district, the amount of the rainfall, and the seasons of the year. The proportion between drainage and rainfall varies in different localities. Experiments made in 1835 upon drainage areas in Eatonbrook and Jamidson brook valleys in the state of New York, by J. B. Jervis, Esq., show that .449 of the total rainfall ran off by drainage. From tables compiled by Mr. Beardmore, C.E., the Thames at Staines carries away .119 of the rainfall of a district composed of chalk, greensand, Oxford clay, oolites, &c. The Loddon carries away .118 of the rainfall from a greensand district. The Nene, at Peterborough, draining a district of oolites, Oxford clay, and lias, carries away .081 of the rainfall. The Wandle, below Carshalton, draining a chalk district, carries away .414 of the rainfall. Mimran, at Panshanger, from the chalk, carries away .435 of the rainfall. Plym, at Sheepstor, from the granite, carries away .335 of the rainfall. Glencorse Burn, flowing from Pentland Hills, carries away .131 of the rainfall. The proportion of rain drained off by rivers is not so great as that which is intercepted and impounded in the reservoirs of some works constructed to take their supplies direct from drainage areas; the reason of which is that the water of rivers is exposed to circumstances favourable to the processes of absorption, evaporation, and animal and vegetable assimilation.

Although the proportional amount of rainfall conveyed away by a river is not so great as that which may be collected direct from a drainage area, nevertheless, the enormous drainage areas of rivers render them extremely useful for taking supplies of water, and it is worthy of note that the majority of the old-established cities and towns of this and other countries have been situated originally upon rivers and streams of various capacities, probably with a view to secure a sufficiency of water for various purposes, as well as on account of their forming a highway or road to facilitate the transit of their commodities, or as a protection and defence from their enemies.

One great drawback to the use of water for the supply of towns is its want of limpidity at particular seasons of the year, which necessitates the use of special measures for its purification. This want of limpidity is owing to the currents of water wearing away the sides and bed of the channel, or conveying the detritus washed from the surface of the land from which it may flow. The mechanical matter thus conveyed by rivers may be divided into two varieties—viz. that which is suspended in the water, and that which it rolls over the bed of its channel by the mechanical force of the current. The amount of matter transported by a river under the latter circumstances depends upon the velocity of the water, the nature of the bottom of the channel, and the shape, character, and size of the particles moved. From experiments made by Bossut, Dubuat, and others, the size of particles conveyed by rivers flowing at different velocities is as follows:

Velocity per Second.	Materials conveyed by Stream.
3 in.	Fine potters' clay.
6 in.	Fine sand.
8 in.	Coarse sand—size of linseed.
12 in.	Fine gravel.
24 in.	Pebbles—1 in. diameter.
36 in.	Angular stones—size of an egg.

The way in which the particles of sand are transported by a river are interesting, and the examination of a sandy bed of running water presents a section of a series of undulations or inclined planes. The up-stream side of these planes is very gentle, while the down-stream side is steep. The grains of sand moved along by the water are forced up the long slope, and when they arrive at the top of the plane, fall down the steep side on to the foot of the next long slope of the undulations below, and so they are conveyed along; thus, in some measure, the rate of abrasion of the bed of the channel is diminished by this action. The matter that is urged along the bed of a channel by the current only influences works for the supply of water in cases where an accumulation of such matter has a tendency to choke or diminish the sectional area of the artificial channels or pipes provided for conveying it, against which provision must be made.

The quantity of matter held mechanically in suspension in the water depends mainly upon the velocity and specific gravity of the matter suspended. In all cases it will be found that the lightest matters are held longest in suspension; and in studying the physical condition of rivers it will be observed that, whenever any circumstances occur that have a tendency to reduce the velocity, a certain amount of the heaviest matters held in suspension will be precipitated; consequently, in rivers unaffected by tides, the lightest matter will be carried the farthest; and if precipitated, will be deposited at the outfall. The following table gives the proportional quantities of matters suspended in some river waters:

Name of authority.	Name of river.	Proportion by volume.	Proportion by weight.
T. Logan, C.E.	Irrawaddy—flood.	$\frac{1}{3984}$	$\frac{1}{1511}$
Do.	" ordinary state.	$\frac{1}{11379}$	$\frac{1}{5752}$
Mr. Ellet.	Mississippi (mean)	$\frac{1}{3000}$	$\frac{1}{1511}$
Mr. L. Horner.	Rhine—flood.	$\frac{1}{24949}$	$\frac{1}{12500}$
Do.	" ordinary state.	$\frac{1}{41288}$	$\frac{1}{20734}$
Do.	" mean.	$\frac{1}{31104}$	$\frac{1}{15598}$
Sir George Staunton.	Yellow River, China.		$\frac{1}{300}$
——	Seine—flood.		$\frac{1}{2000}$
B. Latham, C.E.	Ouse* at Ely—flood.		$\frac{1}{23648}$
Do.	" minimum.		$\frac{1}{888000}$
Do.	" mean.	-	$\frac{1}{119658}$

There are so many circumstances connected with the presence of the mechanical matters held in suspension, that no general rule can be laid down as to the amount that may be expected under certain conditions; yet there are some known circumstances, such as increase of velocity, that favour the acquisition and transportation of such matter. The corroding and abrading action of water is incessantly re-arranging the strata of the earth's crust, and geology teaches us that the same results that are now being produced by the flow of our rivers in conveying the particles of various geological strata from elevated localities to the valleys or the mouths of our rivers have been in active co-operation for countless ages.

QUALITY OF RIVER WATER.

The quality of the river water varies immensely with the character of the district drained, and some river waters, after being freed from the adventitious mechanical matters present, are of great purity, such, for instance, as the waters of some of the rivers of Switzerland, Scotland, Wales, and the north of this country. It has been already mentioned that the quality of river water is a mean between the waters of many sources; the nearer the water supply is taken to the rise or head the purer and freer it will be from organic impurities. Rivers taking considerable supplies from permeable districts, into which the rainfall percolates the strata to various depths before arriving at the river, will contain a larger amount of inorganic matter than rivers deriving their supply from the surface drainage of impermeable districts. River water, as a rule, contains a large amount of organic matter, consisting of minute animal and vegetable organisms, as well as of the matter acquired from the decay of vegetation and from the surface of cultivated lands, and in many instances from the reprehensible plan of turning the sewage of the towns situated upon its banks into the stream. There can be no doubt that a marked improvement would take place in the quality of many rivers if compulsory powers were enforced to prohibit the obnoxious contents of sewers and cesspools being turned into the rivers, which under other circumstances, if properly applied, can be profitably utilised.

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* The amount of matter suspended in the water of the river Ouse, at Ely, is based upon the daily observations of the author, extending over a period of eight months. These observations are tabulated in Plate 2. W.W. shows the height of the water above the datum on the river gauge. The line M.M. shows the impurities; the fine horizontal lines represent the height of water in feet, and also the amount of impurity, as one foot of water in the diagram is made to represent one-tenth of a grain of suspended matter. This diagram is interesting, as it shows to the eye at once the effects produced by an increase of water in the river, as connected with every rise of water there was found to be a corresponding increase in the amount of mechanically suspended matter present in the water.

River water, taken at points removed from the centres of great populations, or from highly cultivated lands, is often very good in quality, and, being generally well aërated, is highly esteemed; the great drawback to the use of it is the variableness of its quality and temperature. These matters, together with the various modes of purifying river water, will be considered hereafter; but the following table gives a list of the impurities present, and the analysis of the water of some rivers:—

Name of river and authority.	Carbonate of lime.	Sulphate of lime.	Carbonate of magnesia.	Sulphate of magnesia.	Chloride of magnesia.	Sulphate of soda.	Carbonate of soda.	Chloride of sodium.	Sulphate of potassa.	Nitrate of potassa.	Nitrate of soda.	Nitrate of magnesia.	Phosphates, earthy.	Alumina.	Oxide of iron.	Silicic acid.	Organic matter.	Total.
Clyde, Penny......	2.52	.26	.72	...	.40	1.94	...	.54	1.94	...	...	...	.31	.28	Trace	.28	.89	7.86
Severn, do..........	.50	.52	...	...	.66	.39	...	.73	.39	...	...	...	.18	.32	...	.32	.45	3.75
Seine, Deville......	11.609	1.886	.189	Trace	...	...	...	.862	.35	...	.659	.364	...	.035	.175	1.711	...	17.84
Rhine, do.	9.511	1.03	.350	...	...	.946	...	.14	...	2.66	...	...	...	.175	.406	3.423	...	16.247
Garonne, do.	4.524	...	.238	...	...	.371	.455	.224	.533	...	...	...	...	...	.217	2.813	...	9.585
Loire, do.	3.374	...	.427	...	...	.238	1.423	.336	...	...	...	...	...	.498	.385	2.848	...	9.437
Rhône, do.	5.334	...	3.43	...	...	.519	...	.119	...	.28	.315	...	.333	...	...	1.669	...	9.082
Doubs, do.	13.397	...	.161	...	.035	.357	...	.161	...	.287	.273	...	...	.147	.21	1.114	...	16.142
Thames, Letheby .	11.10	4.78	...	...	...	.48	...	1.88	...	...	...	...	...	.76		1.0	2.75	22.75
Ouse (Ely), do. ...	13.0	10.39	...	...	.37	1.01	...	2.50	...	3.40		...	...	.67		.12	1.34	32.8
Lea																		23.7
Colne																		21.3
Trent	.32	21.55	5.66	...	...	...	...	17.63	...	...		...	Trace	.50		.72	3.68	50.16
Dee..................	.85	.12	.36	...	...	...	...	.72	...	...		...	Trace	.06		.14	1.64	3.89
Don..................	2.23	.13	1.07	...	...	...	...	1.26	...	...		...	Trace	.27		.52	3.0	8.54

The following is a list of some of the towns of this country that derive their water supply from rivers and streams :—

Name of town.	Quantity of water used daily.	Name of river or stream.
Banbury	120,000 gallons	River Cherwell
Barnstable	120,000 „	A brook
Carlisle	1,000,000 „	River Eden
Chester	900,000 „	River Dee
Dublin	12,000,000 „	River Vartry
Durham	350,000 „	River Weir
Ely	300,000 „	River Ouse
Exeter	960,000 „	River Exe
Hereford	220,000 „	River Wye
Ilfracombe	30,000 „	A stream
Leamington	300,000 „	River Leam
Leek	200,000 „	A stream
Lynn	1,000,000 „	Do.
Middlesborough and others	———	River Tees above Darlington
Newark	150,000 „	River Trent
Penrith	300,000 „	River Eamont
Perth	250,000 „	River Tay
Southampton	1,800,000 „	Partly from river
St. Thomas the Apostle	90,000 „	River Exe
Stockton	———	River Tees
Torquay	360,000 „	Dartmoor
Wakefield	400,000 „	River Aire
Wellington	———	Wrekin Brook
Wolverhampton	1,250,000 „	River Worf
York	1,306,000 „	River Ouse

SUPPLY FROM NATURAL SPRINGS.

It has been already observed that many rivers receive a portion of their supply of water from springs; consequently, those towns which use the water of rivers are literally deriving a supply partly from springs and partly direct from drainage areas—for the permanent flow of a river is due to its receiving large accessions of water from springs. It may sometimes occur in practice that a spring itself may be taken advantage of to furnish a supply of water; or if the natural flow of water from such spring is insufficient of itself, yet, as it may indicate the source of a more copious supply, no paper on water supply would be complete without an inquiry into the theory of springs.

It has been shown that the amount of rain falling on elevated localities is more than on low table-land; the flow of water from springs is due to the rainfall that has been absorbed by the porous strata of the highlands of a district into which it percolates, until intercepted by some impervious bed of strata, by which it is retained in the porous strata, and compelled to traverse it in the direction of its inclination, until at length it may make its appearance at the surface of the ground at a point somewhat lower than that at which the meteoric water was received. The power that impels the rain through the porous strata is hydrostatic pressure, which in some measure is modified by the friction and the capillary attraction of the strata through which the water flows. Springs are kept constantly flowing, by repeated rainfalls and the modifying influences of the strata already mentioned. The permanency of a spring is consequently closely allied to the character and extent of the strata through which the water may flow. If the strata is of an open or porous character, and of but small extent, the springs flowing from it will vary much in their delivery, and will, in all probability, become intermittent in their flow. If, on the other hand, the

the ingredients composing the strata of the earth, and form compounds readily soluble in the percolating water. The value of spring water for domestic purposes depends upon its freedom from the compounds of earthy salts, and from organic matter; and in making choice of a supply, if the springs of a locality are found to contain a much larger per-centage of foreign matter than a source that may be made available at a somewhat greater cost in the construction or working expenses, it may be economy to abandon the near spring for another source. This selection of the source often furnishes a nice point for the engineer to decide, but there are certain well-defined points bearing upon the quality of water procured from various sources that will be considered hereafter, which should be the guide of the engineer in making his selection.

WELLS.

The art of well-sinking is common to all countries, and was probably one of the earliest artificial means adopted to furnish a supply of water. From the earliest periods of history the records of both sacred and secular writ go to prove that the art was pursued alike by the savage who roamed the desert, and the citizen who inhabited the town; yet it should be here observed that there is a marked difference between the mere hole the savage may scratch in the sand, and the highly finished wells of some Eastern cities. So ancient are wells, that Ewbank observes they must have been of antediluvian origin; and that such useful works remain long after the destruction of those more splendid edifices that have been erected, more for the glory than the usefulness of mankind. The buried cities of Nineveh, Herculaneum, and Pompeii, abound in wells of excellent construction, containing good water, and which at the present day supply the inhabitants living in those localities. It is probable that the first wells were shallow holes excavated in the loose soil in moist places, such as are found at the present day to be executed by uncultivated or uncivilised nations or tribes. After the discovery of the metals, which is supposed to have taken place in the seventh generation, as Ewbank observes, rock and indurated strata no longer offered an impediment to the well-sinker, and, consequently, wells were sunk to greater depth in such strata. As the art of well-sinking developed itself at an extremely early period, and long anterior to the commencement of history, no very great advance has been made in it; indeed, the mode usually adopted at the present day when sinking wells to a great depth in loose strata, by first forming a curb on which the ordinary steining is placed, and which settles down as the work of excavation is carried on within, and thereby preventing the loose soil falling into the well, was practised ages ago in sinking wells in the East, and from them we have copied the mode in more modern times. Wells of excellent construction abound in Hindostan, China, Japan, Tartary, Egypt, and elsewhere. When the British took possession of Hindostan, the number of wells in use in that country was estimated at 50,000. Many of the ancient wells were of great depth. The wells of Cabaul are from 300 ft. to 350 ft. deep, and many of them are but 3 ft. in diameter. The famous well at Tyre is said to be 630 fathoms in depth. Jacob's well at Samaria is 105 ft. deep, and 9 ft. diameter. The well Zem-Zem, at Mecca, is 210 ft. deep, and that of Joseph, at Cairo, 300 ft. deep. The well of Joseph (Plate 3, Fig. 1) is a fine example of the skill and boldness of design of the well-sinker. Although called after Joseph by the Arabs, it is by no means of so ancient a date as the name would imply, for the well was probably sunk about 700 or 800 years ago, but by whom is a disputed point; some attributing it to a Vizier of the name of Joseph, others to Saladin, the intrepid defender of his country, whose name was Yussef (Joseph). The well consists of two shafts, one above the other, but not in the same vertical line. The upper shaft is an oblong excavation 24 ft. by 18 ft. and 165 ft. deep, descending into a large and capacious chamber, in the floor of which is constructed a basin or reservoir for containing water that is raised from the lower shaft. In this chamber a lower shaft is sunk, which is an excavation 15 ft. by 9 ft. and 130 ft. deep. Round the upper shaft a spiral passage, 6 ft. 4 in. wide and 7 ft. 2 in. high, is cut, separated from the well by a partition wall of the solid rock, only six inches in thickness, through which loopholes are pierced for lighting the passage. This passage is made use of by parties who draw water, and also for the descent of mules or other animals that are employed in the large chamber below, to give motion to a system of chain-pots by which the water is raised from the lower shaft and poured into the basin in the chamber. There is also a spiral passage round the lower shaft, but it is not enclosed from the well as in the case of the passage round the upper shaft. The water of this well is procured from a bed of gravel after penetrating the strata to the depth before mentioned. Wells are common in Greece, and in the olden times of its classic glory were the places of public resort; just as in modern times men congregate at their clubs and such-like places, so did the sage Athenians meet together at their wells, and at them orators declaimed, and music and dance lent their charms to make them places of pleasure and amusement.

The Romans had a clear knowledge of the art of well-sinking, and wells executed by this people are found in every country they once possessed. Many of the successes of their arms were due to their knowledge in this branch of engineering, as when every other source of water failed or was cut away by their enemies, they had recourse to well-sinking to obtain their supply. It was the knowledge of well-sinking that enabled Cæsar to retain Alexandria when all the water of the cisterns had been spoiled by the Egyptians. The same knowledge enabled Pompey to procure a supply of water when holding a position of great advantage against Mithridates, who had abandoned it for want of water. Imperial Rome (prior to the time of Appius Claudius) was supplied with water principally from wells.

The water procured from wells is rain that has descended by the minute interstices of the earth's crust, and is stored in the numberless interstical spaces of a porous strata.

Wells may be classified under two heads—viz. *Ordinary Wells*, or those sunk into permeable or water-bearing strata, and *Artesian Wells*, or those sunk or more generally bored through impermeable strata until a water-bearing strata is tapped, when the water is forced upwards by virtue of the hydrostatic pressure due to the superior level at which the meteoric water was received.

Ordinary Wells may be again classed under the respective heads of *Shallow* and *Deep Wells*. The water from both classes is procured under precisely the same circumstances, but differs often very materially in quality and quantity.

Shallow Wells include ordinary domestic wells sunk a few feet into the permeable strata of the earth's crust, and, owing to their shallowness generally, only catch the adjacent percolating water, consequently cannot be depended upon to give a large supply; and, inasmuch as they are generally contaminated with the contents of sewers and cesspools when sunk in the superficial deposits under cities and towns, which are honeycombed with such offensive receptacles, or tunnelled with imperfect and leaking sewers, their waters are not to be recommended for general use.

Deep Wells sunk into permeable and water-bearing strata derive their supplies from a more remote and extensive drainage area brought into action by the depth given to the wells, the quantity of water yielded by them is limited by the friction of the water in passing through the interstical space and the molecular attraction of the strata for retaining the water, which practically limits the area draining into the well.

Artesian Wells have ages ago been in use, and the antiquity of boring wells of this class is so great, that the precise period of their introduction is unknown. They are common to Syria and Egypt. China abounds with them, many being upwards of 1800 ft. deep and but 6 in. diameter. They are common in Italy and France; and in the province of Artois, of the latter country, they are so abundant that one may be found at nearly every door; and it is from this province that the art of sinking or boring such wells came into this country, and they are named by us after that place. Artesian wells are artificial springs, and the same remarks that apply to springs will apply to Artesian wells.

The quantity of water yielded by wells cannot be absolutely computed, as it is dependent upon so many varying circumstances; but in considering this part of the question we must have regard to the area of drainage, the nature of the stratum, its dip, strike, faults, absorbent properties, and the nature of the underlying and overlying strata, the rainfall, and the depth of the well itself.

The theory of the probable quantity of water yielded by wells is called the cone theory; *i.e.* the drainage area contributing to the supply of a well is represented by an inverted cone, the apex of which is at the bottom of the well, so that if the strata were perfectly uniform, and the flow through it equable, the quantity yielded by wells sunk to various depths would be represented by the area of the different cones; but inasmuch as perfectly uniform strata of any great extent is rarely met with in nature, it is impossible to lay down any but general laws in studying the probable yield of water by wells.

Physical Properties of the Strata.—The yield of water from a well depends upon the nature of the strata; thus, if the strata is of a close texture having but few and small interstical spaces, the drainage area is limited by the friction of the water in flowing through it, and by its capillary attraction; consequently in strata of this character the area contributing to the supply of a well will be represented by an inverted cone of acute angularity; while on the other hand, if the strata has large and numerous interstical spaces, it will yield water rapidly, and the area contributing to supply such well becomes practically infinite. And just in proportion as strata approach one or other of the descriptions of the strata mentioned (all other things being equal), so will the supply of water capable of being procured from wells sunk into them vary. The construction of a well will also influence the flow of water, as, for instance, when a well is sunk into dense but permeable strata containing much water, naturally yielding it slowly owing to the fineness of the interstices; by special arrangement an increased supply could be procured; these arrangements consist generally of long tunnels or headings, driven or extended horizontally, sometimes to great distances from the shaft. They have the double advantage of not only offering a greater surface to allow of the escape of water into the well, but they also act as reservoirs for storing it, which is a great advantage in all cases, but more especially when the water is required at intervals and not continuously. Theoretically, the effect of tunnels or adits is the same as produced by deepening the well; as, according to the cone theory, the space included in the drainage area between the bottom of the well and the surface of the ground, represents the frustrum of a cone; consequently the same drainage area contributes to supply a well with adits as would supply a much deeper well without adits, as the apex of the cone representing the drainage area in the case of a well with adits is at a point lower than the actual bottom of the well. The nature, character, and position of the water-bearing strata, from which wells derive their supplies, must be carefully considered by every person who desires success to crown his labours in practising the art of well-sinking. It has been already shown, under the head of absorption, that the quantity of water sinking deep into the ground is influenced by many circumstances, and is not alone dependent upon the character of the strata; yet it is quite obvious to the most casual observer, that the nature of the strata has the most important bearing upon the quantity and quality of water yielded by wells; thus chalk, from its absorbent nature, has been found by observation on the steep chalk hills around London to absorb a rainfall of two inches per hour; the red sandstone formation, under suitable circumstances, also absorbs rainfall very rapidly, while the more impervious strata absorb it but slowly. The dip or strike of the strata will also have an important bearing upon the amount of water yielded by a well, as it may occur that the natural inclination of the strata may be unfavourable to the yield of any great quantity of water in a particular locality, as shown in Plate 1, Fig. 7.

Faults have a material influence upon the flow of water in the subterranean passages of the earth, and, consequently, have much to do with the amount of water capable of being yielded by wells. The level of the water in the same strata when disjointed by a fault is no longer the same, but may vary considerably, as shown in Plate 1, Fig. 11, and it may also often happen that a well may turn out to be a failure owing to the near proximity of a fault cutting off and diminishing the drainage area. The careful study of the strata should always form an important point in considering the desirability of well-sinking, and the want of such study often entails failures which we ascribe to faults; but the probability is that with further insight and clearer knowledge, many of these failures (which are rather the fault of the engineer than any fault in nature) would not arise. Water flowing in the bowels of the earth follows the same laws as water flowing on the surface of the earth, except when modified by some disturbing cause. The line of saturation, or the level at which water may be procured, varies in different strata, and is affected by various causes; thus the effect of continuous pumping in a district is to lower the water level of such districts. Generally the water level in strata has an inclination in the direction of its flow; thus it has been established by the Rev. Mr. Clutterbuck and others that the inclination of the line of saturation in the chalk in the north of London is 13 ft. per mile. In other places it varies according to circumstances; thus, it is not improbable that the flow of some intermittent springs is due to the elevation in the line of saturation, as in the Bourne at Croydon, which breaks out occasionally after very heavy and continuous rains. As a rule it will be found that in those districts in which the flow of water from springs, and the flow of rivers, is equable, or neither subject to excessive floods nor droughts, but is always discharging very near the mean flow, that wells sunk into the particular strata from which these rivers or springs derive their principal supplies will yield the largest quantity of water.

QUALITY OF WELL WATER.

The character of well water is fixed by the geological strata through which it flows—for as the water is making its way through the bowels of the earth, sometimes travelling a considerable distance, it dissolves more or less of the materials of the crust of the earth in its passage, and becomes impregnated with the soluble portions; on this account, well waters are never perfectly free from foreign substances, volatile or solid, which impress upon the water its character. The water of shallow wells of towns is invariably impure, owing to the infiltration of decomposing matters, which may to some extent become oxidised and decomposed in passing through the soil, and the gases evolved, after further oxidation, combine with the materials it comes in contact with in its passage; which being rendered soluble by this means, add greatly to the impurities present in the water. Thus the shallow wells of towns invariably contain a large quantity of nitrates in solution; they also often contain organic matter in the shape of animalculæ and fungi, the presence of which, if not directly injurious, is indicative of the presence of other matter highly objectionable, if not prejudicial. Although the soil has great power in oxidising the most objectionable matters before they enter the wells, it is by no means certain that the earth can retain this power for any length of time, especially as the sources of contamination are multiplied; indeed, there is ample evidence to show that this power of the soil is limited; as for instance, the cases mentioned by Sir James MacGregor, who relates that when the British army was in Spain 20,000 soldiers were buried in a short space of time in rather a small piece of ground, and the effect upon the adjacent wells was such that the troops who made use of the water of those wells were attacked with malignant fevers and dysentery. The water of deep wells is generally freer from organic matters than that of shallow wells, but it generally contains an amount of mineral matter. The waters of deep wells, on account of their freedom from organic matters, are generally very agreeable as drinking water, if of proper temperature, but for some purposes they are objectionable on account of their hardness.

Composition of Well Waters.

	London shallow wells.	Ely upper part of city.	Ely lower part of city.	Burton on Trent.	Croydon.	Braintree.
Carbonate of lime	30.50	25.10	37.50	15.51	15.41	2.40
Carbonate of magnesia	...	...	...	1.70	.61	11.30
Sulphate of lime	8.20	18.36	52.34	18.96	.53	
Sulphate of magnesia	...	...	...	9.95	...	.70
Chloride of magnesia............	...	.18	2.61	...	...	
Chloride of sodium	12.30	10.88	44.90	10.12	1.51	44.00
Alkaline sulphates................	14.70	16.97	24.37	7.65	1.03	
Alkaline nitrates..................	16.70	28.88	36.86	...	...	12.80
Iron alumina	1.10	.71	.84	.60	...	Traces
Silica	...	.14	.13	.79	.93	1.30
Organic matters	...	.68	.53	...	1.09	
Total........................	83.50	101.90	200.08	65.28	21.11	72.50

Temperature of Well Waters.

The temperature of water taken from the bowels of the earth is somewhat higher than that of waters found upon the earth's surface. The rate of increase has been variously estimated: thus, Mr. Paterson, in a magazine published in 1839, states that the mean temperature increases in the case of eleven wells sunk in Scotland about 1 deg. Fahrenheit for every 48 ft. descent. M. Valferdin found that in some wells in Paris the rate of increase was 1 deg. for every 57 ft. descent. M. de Girardin found at

Rouen that the rate of increase was 1 deg. for every 37½ ft. of descent; and in another case 1 deg. for 55½ ft. descent; while careful experiments on the Artesian well at Grenelle give an increase of 1 deg. for every 59 ft. descent. The mean temperature taken from the above observations would give a mean result, showing that the rate of increase of temperature as we descend is 1 deg. Fahrenheit for every 52 ft. descent. Owing to this rate of increase in the temperature of water taken from deep wells, when the well is very deep and the increase in temperature very great, the water is totally unfit for many purposes, and this fact should be taken into consideration when deciding on a source of supply. The temperature of the water at the well of Grenelle, which is nearly 1800 ft. deep, is 81.81 deg. Hospitals and public baths have been heated with it.

FORM OF WELLS.

Various forms of wells have been made at different times, and under varying circumstances, and in all ages. The square, oblong, ellipse, and circle have all been used with success. Such of the wells of the East as were executed in solid rock and without steining, are sometimes in the form of a square, sometimes oblong (as Joseph's well), and sometimes circular, but of all the forms the circle is the best. The ellipse can be used in some special cases with advantage, but for all practical purposes the circle is by far superior to any other form, as a well of this form can be bored or misered to great depth under water. It requires less steining than any other form or shape of well of equal area, and its form is the best for withstanding the lateral pressure of the earth, as a strain on a particular part is mutually sustained by the whole steining.

MATERIALS USED IN THE CONSTRUCTION OF WELLS.

The sides of wells require lining or steining (as it is termed) with some material that will prevent the loose strata of the sides of the excavation falling into the well and choking it. The materials that have been successfully used in this work are brick, stone, timber, and iron. Each description of material is suitable under certain conditions, while in other positions it is objectionable. Brickwork, which is universally used in steining wells in this country, not unfrequently fails in certain positions; as by reason of admitting impure water when such water is under great pressure, or from the work becoming disjointed from settlement due to the draining of a running sand bed, or the collapse of the well. Stone of good quality, capable of withstanding compressive strains, is good in its way; but, inasmuch as it requires an immense amount of labour to fit it for its place, it cannot successfully compete with brickwork in the formation of wells, more especially as it has no merits superior to those of brick when used in such work; however, if in any locality, by reason of its cheapness, it can be used, care should be taken to select only such samples as contain a large amount of silica; indeed, in all cases it is a point of great importance in studying the nature of the materials used in the construction of wells, to select those which are likely to be the most durable, and at the same time preserve the purity of the water contained in the well; and this is best secured by silicious materials. Timber is objectionable as a material to be used in the formation of wells, on account of its liability to decay, and thus not only endanger the construction of the well, but likewise to some extent foul the water by such decay. It is very largely used under some circumstances, especially in the preliminary operations in sinking most wells. It is also successfully used in lining the shafts of the salt wells of Cheshire, and will continue entire in such a position for a great number of years, as the brine seems to have a tendency to preserve the timber and prevent its decay. Iron is of modern application, and is a material extensively employed in steining wells; and, as it possesses many advantages over materials ordinarily used, its use is likely to be much extended. It possesses all the qualities of a good material, insomuch as by its character it is capable of bearing great compressive strains, and of effectually excluding the influx of all such waters as it may be desirable to keep out, and is not liable to decay under ordinary circumstances. The author has known instances where recourse has had to be had to the use of iron cylinders, when it has been found that four or five rings of brickwork, set in the best cement, have failed to keep out brackish waters; and, if the original design had provided for the introduction of these cylinders, it would have reduced the cost of the well very materially.

The introduction of iron as a steining for wells, whether in the form of cast or wrought iron cylinders, under many circumstances, will always be attended with economy and success. The well-sinker of the present day has often, in executing his work, to contend with the presence of large volumes of water, which, under ordinary circumstances, must be got rid of by pumping; but, by the introduction of iron cylinders, which can be sunk under water by the aid of the boring tool and miser, the consequent expense of pumping is saved. It will be entirely a matter of calculation whether or not they should be used; but generally, and when no special object is required to be fulfilled, brick steining is the cheapest; though when the strata is particularly treacherous it is decidedly the best to have recourse to iron. Iron cylinders are absolutely necessary in sinking through sand charged with water; otherwise, if there is a current of water produced, the sand flows with it into the well, which is objectionable, as the sand speedily destroys or injures the pumps—moreover, it is attended with a more serious evil, and that is, the draining of the sand undermines the superincumbent strata, which may lead to the destruction of the well itself, or any buildings erected over it. In some cases where cast iron has been used in wells and the shafts of mines it has been softened by the action of the water, and converted into a species of plumbago. This in itself is not any objection to the use of iron, but rather to the use of such waters that are affected by it if used for the ordinary purposes of water supply for which the well was sunk. If, on the other hand, the action takes place from the attack of water it is desirable to keep out of the well, wrought iron may be substituted with advantage in the place of cast iron, or other measures may be adopted to preserve it. It may be observed that it is but in few cases that this action upon the iron can arise, and, when it does, it is not in those districts in which we must rely upon wells for obtaining a supply of water.

Copper was one of the early materials used in lining the bore-holes of Artesian wells, but of late years iron has entirely superseded it in this branch of engineering.

MODE OF SINKING WELLS.

In sinking ordinary wells in loose strata, an excavation is made to such a depth as the strata will admit without falling in. A wooden curb is then placed in the bottom of the excavation, and the brick steining laid upon it, and when carried up to the surface, the work of the excavation is carried on; but the way in which it is now proceeded with depends upon the method adopted in extending the steining. If the steining is intended to be added below the curb, the earth is excavated flush with the interior sides of the well, so that the earth underneath the curb supports the brickwork above. When the excavation has been carried on as far as convenient, recesses are made in the earth under the previous steining, and in these recesses the steining is carried up to the previous work. When thus supported the intermediate portion of earth between the portions of brickwork carried up are cut away and the steining completed. By a succession of operations of this kind the well is sunk and the steining carried to the required depth. On the other hand, if the steining is added from above, the curbs are supported by iron rods, fitted with screws and nuts from cross timbers over the mouth of the well, and as the excavation is carried on below, brickwork is piled on above, and the weight of the steining will carry it down as the excavation proceeds, until the friction of the sides overpowers the gravitating force or weight of the steining, when it becomes, as it is technically called, earth-bound; then a set off must be made in the well, and the same operation repeated as often as the steining becomes earth-bound, or recourse must be had to the first method of under-pinning. Brick steining is executed either in bricks laid dry, or in cement; when the work is laid dry, a ring or two of brickwork in cement is often introduced at intervals varying from 5 ft. to 12 ft. apart to strengthen the work and facilitate the construction of the well. The bricks are laid flat, breaking joint; and to keep out moderate land springs, clay, puddle, or concrete, is often introduced at the back of the steining; for most purposes concrete is the best, as, in addition to its impervious character, it adds greatly to the strength of the steining.

The same measures are used in sinking iron cylinders as are adopted in sinking brick steining. Generally the cylinders are made of cast iron, either cast entire or built up of several shutters; the cylinders have internal flanges by which they are secured together, and which add very much to their strength; they are usually fastened together by bolts, and the joints are caulked with iron cement. Cylinders of this description, when they become earth-bound, can be driven so that they may be sunk to considerable depths without much trouble. The cast-iron pipes used in lining the bore-holes are put together with collars sunk into a recess at the ends of the pipes, or cylinders, and to which they are secured by countersunk screws, so that both the external and internal face of the cylinder is flush, and offers no impediment either to their being sunk or to the flow of water. When the supply is taken from sand it is usual to perforate the pipes, but this is not necessary in most strata; indeed, in the bore-holes in chalk and sandstone, or other strata that will stand without artificial support, it is not usual to line or stein except in cases where it is desirable to shut out some particular water.

BORING WELLS.

The art of boring wells is evidently more modern than the practice of sinking, yet it is of so remote a date that the precise period of its introduction is unknown. Wells that have been bored are common in China, Syria, and Egypt; and many of them are supposed to have been executed 4000 years ago. In France, the earliest authenticated well is at Lillers, supposed to have been executed in 1126. In boring wells two systems have been adopted: one is called the Chinese system, and consists in having the boring tool attached to a rope; the other is the ordinary method, in which the boring tools are attached to a rod of iron or wood. Although these are the two primary ways adopted in boring, there are many modifications of them in practice combining one or other method; indeed, every engineer or contractor may have his own particular mode, or the circumstances connected with each work may demand the introduction of particular measures. (Plate 3, Figs. 2, 3.)

The method designated the Chinese is the simplest that is practised, as all the boring tools are attached direct to the rope worked vertically up and down, the torsion of the rope giving sufficient rotary motion to the tool to enable it to strike a fresh spot at every descent. The facility with which the tools can be raised by the rope in this system seems at first to commend itself; but in practice, when sinking deep wells, it is open to serious objections, as, owing to the flexibility of the rope, the tool cannot be properly guided, and the bore-hole is likely to become crooked, which would in time interfere with the working of the tool; and in cases where the bore is to be lined with pipes, would render difficult, if not prevent, their insertion.

The ordinary plan adopted in boring is to attach the tools to a rod, consisting of a number of lengths jointed together; a vertical and circular motion is given to the rods. In deep wells much time is necessarily lost in raising and lowering a long length of rod, either to change the tool or bring up the débris. Various attempts have been made to economise the time thus spent; as, for example, it has been proposed to make the tools slide upon the square boring rods, and by attaching them by chains or ropes to a windlass, when they require raising, it could be speedily done, as in the Chinese system; because it would not be necessary to unjoint the rods, as required when using the ordinary tool. Another method, patented by Beart in 1844, was to make the rod of the boring tube hollow, and into this tube to introduce water, which, ascending outside the boring tool, was to produce a sufficient current to carry the materials, loosed by the boring tool, to the surface. A very great objection to this method (even supposing it to be practicable) is the necessity of having a large volume of water, which generally in boring cannot be easily procured until the spring is tapped.

In boring deep wells the weight of the rod and the force of the momentum in falling are very likely to break the tools used, or the rods themselves, when special provision must be made to prevent it. This has been attempted in various ways. Thus, wooden rods hooped with iron have been substituted for the iron bar—tubular iron rods have been used, having the same weight per foot as the ordinary bar, but having a greater area; when working in water they lose a portion of their weight, equal to the volume of water they displace. Both wooden and tubular rods will answer very well when the depth is not great, but when the depth is great they are not sufficient to meet the exigencies of the case. When a sliding joint is used (Plate 3, Fig. 4)—this joint was introduced by Œuyenhausen, in Germany, M. Kind, in France, and in the system known as Kind's system in this country—any portion of the entire weight of the rods can be brought into action, as all those rods above the slide joint are counterbalanced by a weight suspended to a lever. In Kind's system the rods are often put in motion by a steam-engine, in the following way:—The rods are attached to one end of a lever resting on a fulcrum, the other end of the lever is attached to the piston-rod of an upright steam-engine; the valves of the cylinder are worked by a man; the rods are lifted by steam pressure and fall by their own weight.

The tools used in boring (Plate 3, Figs. 5 to 12, inclusive) differ according to the description of strata they are required to penetrate. Thus, when the strata is hard and compact, chisels of various descriptions are used to loosen the materials, which are either raised with an auger or shell pump, or miser. When the materials are of a soft nature, augers of various kinds are used.

It very often happens that in deep borings it is almost impossible to escape breaking the tools used; when special instruments have to be used to raise them. (Plate 3, Figs. 13, 14, 15.)

TOWNS SUPPLIED FROM WELLS.

The art of well-sinking in a great measure may be said to be empirical, and it by no means follows that because water is procured in some places from wells and borings in sufficient abundance to supply a town, that water can be procured anywhere by sinking or boring, as it requires a combination of circumstances not generally met with to render the work successful; and as all theory when applied under unknown circumstance may lead to error, a collection of examples of wells in use at various places where water is raised for public purposes will be highly useful in guiding us in estimating the quantities of water likely to be procured under given circumstances.

Birkenhead, Cheshire, is supplied with water from two wells, 395 ft. deep, partly sunk and partly bored in the new red sandstone formation. From experiments made upon one of these wells, when the water level was 120 ft. from the surface, the well yielded 1,807,461 gallons in twenty-four hours; by lowering the head another 4 ft., the well yielded 2,000,000 gallons in twenty-four hours.

Braintree, Essex, is supplied with 45,000 gallons of water per day, from a well sunk and bored in the chalk. The well is 9 ft. diameter, and 55 ft. deep, with a bore-hole at the bottom 340 ft. in depth, making the total depth of the well 395 ft. In this well the water level has been observed to rise with every rise of the tide, which is probably due to the hydrostatic head created by the tide impeding the free flow into the sea of some under current, which is consequently dammed back, owing to the increased resistance offered to its escape.

Brighton, Sussex, is supplied with 1,080,000 gallons of water daily from wells sunk into the chalk.

Bury St. Edmunds, Suffolk, is partly supplied from two wells sunk in the chalk to a depth of 86 ft., and connected by headings. There is about 130 ft. of heading, 6 ft. × 6.5 ft., in connexion with the two wells. Very accurate observations have been made upon the level of the water in these wells by Mr. John Croft, in the year 1860, and continued to the present time, and are tabulated in Plate 4. Observations made by the same gentleman on a hundred private wells sunk into the superficial strata of the town show that the water level in all is very nearly the same, and varies in any case but a few inches. The wells upon which these observations have been made were sunk by the local authorities, not with a view of supplying the inhabitants with water, but for the purpose of procuring a supply of water for watering the roads, and other public purposes; but since the original construction of the wells a portion of the town has been supplied. The quantity of water yielded by these wells fluctuates greatly, and is dependent upon the season of the year. Thus upon one occasion, after a trial continued over seventy consecutive hours, the well yielded water at the rate of 150,000 gallons every twenty-four hours; but the ordinary quantity supplied is about 60,000 gallons per day.

Coventry, Warwickshire, is supplied with 750,000 gallons of water per day from two bore-holes made in the bottom of the reservoir, 100 ft. diameter; the bore-holes are respectively 6 in. and 8 in. diameter, and 200 ft. and 300 ft. deep. The supply is procured from the red sandstone; and, from observations made, it has been found that the two yield water at the rate of 700 gallons per minute.

Croydon, Surrey, is supplied from two wells sunk into the upper chalk, one being 75 ft., and the other 150 ft. deep. The latter well was sunk by Mr. Thomas Docwra, under the author's direction; and although sunk but 56 ft. from the old well, it has been proved, by careful experiments, that there is very little communication between the main body of the water in the two wells. Thus, when water at the rate of 1,000,000 gallons per day was being raised from each well, the relative water level in the two wells was not the same, but was 7 ft. lower in the new well than in the old. By stopping the pumping operations in the new well, and continuing them in the old, the water level in the new well rose 5 ft. above the water level in the old well, proving the two wells to be independent of each other. The quantity of water yielded by the old well during the last dry summer was at the rate of 1,500,000 gallons per day, and was only limited to this quantity on account of an insufficiency of steam power to raise more.

Dorchester is supplied with 180,000 gallons of water per day, from a well 120 ft. deep sunk into the upper chalk; the well is furnished with four headings, having a total storing capacity of 70,000 gallons.

Eastbourne, Sussex, is supplied with 200,000 gallons of water per day, from two wells partly sunk and partly bored 125 ft. into the upper greensand; the wells are provided with a heading capable of containing 10,000 gallons; the bore-holes are 7 in. diameter, and 60 ft. deep.

Enfield, Middlesex, is supplied with 90,000 gallons of water per day, from a well sunk and bored 215 ft. into the lower chalk; the bore-hole is 12 in. diameter, and 201 ft. deep.

Fareham, Hampshire, is supplied with 200,000 gallons of water per day, from two wells 12 ft. and 9 ft. diameter respectively, which have an adit or heading in connexion therewith capable of containing 30,000 gallons.

Kingston-on-Hull, East Yorkshire, was formerly supplied with river water, but during the present year (1864) the town has been supplied with water raised from a well sunk at Springhead, and forced by steam power to the old works at Stone Ferry, a distance of nearly five miles, from which place it is again pumped and distributed to the town. The well is sunk and bored in the chalk to a depth of 281 ft. 6 in., of which 210 ft. is an 18 in. bore. The well itself is 14 ft. diameter, and steined partly with iron cylinders and partly with brickwork. At the present time the well is yielding 3,500,000 gallons for the supply of the town; the water available is estimated by Mr. Thomas Dale, the engineer for the works, as not less than 4,000,000 gallons in twenty-four hours. Owing to the large influx of water, and the position of the pumps, special measures have been taken by the engineer to shut out the water from the well when an examination of the pump valves is necessary. This is effected by lowering a conical weight weighing five tons into the bore pipe, the bottom of the well being covered with cast metal plates secured to the sides of the well and to the bore pipe. With this plug in the bore pipe it is found that one pump will keep down the water while any repairs are required to be made to the other pump. In sinking this well it was observed that the water was obtained from the under side of the layers of flint intersecting the chalk.

Liverpool, Lancashire, is partly supplied with water from wells sunk in the new red sandstone formation. Some of these wells yield as much as 3,250,000 gallons daily.

Margate, Kent, is supplied with 200,000 gallons of water daily, from a well 13 ft. diameter, and 50 ft. deep, sunk into the chalk; the well has a heading 400 ft. long, 9 ft. high, and 4.5 ft. wide.

Northampton is supplied with 518,400 gallons of water per day, from a well partly sunk and partly bored 250 ft. deep into the lias formation. (Fig. 37.)

Nottingham, is supplied with 2 million gallons of water per day from wells sunk into the new red sandstone.

St. Helen's New Waterworks derive their supply of water from two wells sunk in the red sandstone. Each well is 210 ft. deep, exclusive of the bore, and they furnish a supply of 572,000 gallons of water daily.

Salisbury, Wilts, is supplied with 600,000 gallons of water per day, from a well sunk in the chalk. The well is 8 ft. diameter, 50 ft. deep, and furnished with a heading 70 ft. long, 6 ft. high, and 2.5 ft. wide.

Selby, West Yorkshire, is supplied with 120,000 gallons of water daily, from a well partly sunk and partly bored to a depth of 330 ft. into the new red sandstone formation; the bore-hole of this well is 320 ft. deep, and 7 in. diameter.

Sheerness, Kent, is supplied from a well partly sunk and partly bored 380 ft. deep; it derives its supply of water from the upper greensand formation, and at the restoring of the well it yielded water at the rate of 220,000 gallons every twenty-four hours; the bore-hole of this well is 14 in. diameter, and 80 ft. deep.

Stourbridge, Worcestershire, is supplied with 150,000 gallons of water daily from a well 6 ft. diameter and 30 ft. deep, sunk in the red sandstone formation.

Tranmere, Cheshire, is supplied with 150,000 gallons of water daily, from a well 9 ft. in diameter, and 120 ft. deep, sunk in the new red sandstone.

Trevethin Waterworks Co., Pontypool, furnish a supply of 150,000 gallons of water daily, from springs flowing from the limestone rock.

Uxbridge, Middlesex, is supplied with water from two wells, each being capable of yielding 100,000 gallons per day.

Wallasey, Cheshire, is supplied with 300,000 gallons of water per day, from a well sunk and bored 236 ft. into the new red sandstone formation.

Wolverhampton, Staffordshire, is occasionally supplied with water from three wells sunk in the new red sandstone formation, which yield 500,000 gallons of water per day.

Designs of Wells.

In considering the best mode of constructing a well, many important matters have to be thought of, and some unforeseen circumstances may often cause the original plan to be set aside. Under this head it is proposed to give a brief outline of the construction of a few wells, which may serve as a guide in any similar work.

Amwell Hill Well, New River Water.—(Plate 5, Fig. 1.)—This well furnishes a supply of water equal to 2,460,000 gallons of water per day; it is entirely sunk in the chalk; for 84 ft. from the surface it is steined with 9 in. brickwork, then follows a sinking 10 ft. diameter without steining, but furnished with headings 6 ft. high and 4 ft. 6 in. wide. In the centre of this shaft a 2 ft. bore is made, which is succeeded by one 9 in. diameter. The entire depth of the well is 161 ft.

Birkenhead.—(Plate 5, Fig. 2.)—It has been already mentioned that Birkenhead is supplied with water from two wells; for all practical purposes, a description of the first well sunk will suffice. This well is entirely executed in red sandstone rock, and without steining. The total depth is 395 ft.; the first 95 ft. is 9 ft. diameter, then follows a bore of 26 in. diameter and 44 ft. deep; this is succeeded by a bore 18 in. diameter and 16 ft. deep, which is diminished to a bore of 12 in. diameter for an additional depth of 130 ft., and finally this is succeeded by a bore 7 in. diameter and 110 ft. deep. The water rises, after the cessation of pumping, to within 93 ft. of the top of the well; and, when reduced to a level of 134 ft. from the surface, the well yields 2,000,000 gallons of water every twenty-four hours.

Cheshunt Well, New River Company.—(Plate 5, Fig. 3.)—This well yields 702,000 gallons of water per day, and in its execution the following strata were pierced:—1 ft. 6 in. superficial earth, 8 ft. gravel, 45 ft. blue clay, 2 ft. yellow clay, 12 ft. white sand, 39 ft. dark coloured sand, then follows the chalk. The well is 171 ft. deep, and is steined partly with brickwork and partly with iron cylinders. For 12 ft. in depth the well is 11 ft. 6 in. diameter, and steined with 14 in. brickwork; for a further depth of 44 ft. it is 9 ft. diameter and steined with 9 in. brickwork; of the 44 ft., 41 ft. is lined with cast-iron cylinders, 8 ft. diameter, which are also carried to a depth of 105 ft. from the surface. There are fifteen cylinders of this size in use, and they are succeeded by others 6 ft. 10 in. diameter, of which there are six in use; these are again succeeded by two cylinders, 6 ft. diameter. The whole of the cylinders are 6 ft. in depth. The bottom of the last cylinder is 118 ft. from the surface, at which point they rest upon a foundation of 9 in. brick steining, 7 ft. in depth. At the bottom of the 6 ft. cylinders the well widens out in the form of a cone 12 ft. 6 in. diameter at the floor, which is 26 ft. below the bottom of the 6 ft. cylinders. In the centre of the well a bore-hole 3 in. diameter and 27 ft. deep was made, and the well is provided on the floor level with headings 7 ft. high and 4 ft. 6 in. high.

Cheshunt—Well of Sir Henry Meux.—(Plate 5, Fig. 4.)—This well is 202 ft. 6 in. deep, and derives its supply of water from the chalk. It is an ordinary well, steined with brickwork. The surface water is prevented from entering the well by making the well concentric at the top, the space between outer and inner wells being afterwards filled in with puddle. The well itself is 71 ft. deep, steined with 4½ in. brickwork. It is executed for the remainder of the depth by bore-holes, varying in diameter from 7 in. to 4 in. In executing it the following strata were pierced:—5 ft. gravel, 59 ft. blue clay, 12 ft. coloured clay, 1 ft. dark coloured sand, 5 ft. 6 in. sand and pebbles, 3 ft. bright sand, 35 ft. dark sand, 1 ft. flints, 2 ft. chalk flints, 1 ft. flints, the remaining distance of 78 ft. being entirely chalk.

Guy's Hospital.—(Plate 5, Fig. 5.)—The well is sunk through the London clay into the chalk, and the following is a description of the strata pierced:—8 ft. superficial earth, 2 ft. yellow clay, 1 ft. black loam, 3 ft. peat, 19 ft. gravel, 63 ft. blue clay, 22 ft. mottled clay, 4 ft. dark blue clay, 5 ft. shells and sand, 10 ft. mottled clay, 4 ft. sand and pebble, 4 ft. mottled clay, green coloured sand and pebbles, 4 ft. green coloured sand and pebbles, 3 ft. green coloured sand, 44 ft. grey sand, succeeded by a layer of flints, and then the chalk. The total depth of the well is 298 ft. 6 in. For 9 ft. in depth it is 8 ft. diameter, and steined with 9 in. brickwork; which is succeeded by five cast-iron cylinders, 4 ft. 6 in. diameter, each cylinder being 5 ft. deep. Below these cylinders, and for a further distance of 96 ft., the well is 4 ft. 6 in. diameter, and steined with 4½ in. brickwork, then follows 2 ft. of 9 in. steining, the whole resting on the bottom of the well, which is executed in 18 in. brickwork. In the centre of the well a bore-hole is made, which is lined with a 12 in. iron pipe, the pipe being continued 72 ft. 6 in. above the bottom of the well, and within 60 ft. of the surface.

Kensington Gardens.—(Plate 5, Fig. 6.)—This is a well that was sunk for supplying the Serpentine. It is 321 ft. in depth, and the water rises within 105 ft. of the surface. The following is a description of the strata pierced in making this well:—2 ft. of surface earth, 170 ft. blue clay, 2 ft. petrified wood, 7 ft. dark coloured sand, 43 ft. 6 in. coloured clays, 1 ft. 6 in. sand, 4 ft. pebbles, 30 ft. sand, 3 ft. 3 in. flints, 54 ft. 5 in. chalk, 3 ft. 3 in. flints. The well is 6 ft. diameter for 203 ft. deep, and steined with brickwork as follows:—For the first 25 ft. with 9 in., 67 ft. 6 in. with 4½ in., 5 ft. with 9 in., 10 ft. with 14 in., 5 ft. with 9 in., 91 ft. with 4½ in. The remaining portion of the well is lined with 4 ft. 6 in. iron cylinders; there are twenty-three of these cylinders in use in the well, and they are continued up the well within the brick steining, a distance of 60 ft. The bottom of the well is filled up with concrete, through which a boring is made and lined with a 12 in. pipe, 18 ft. in length; the top of the pipe is about 5 ft. above the bottom of the well; the remaining portion of the boring is lined with an 8 in. pipe.

Northampton Waterworks.—(Plate 5, Fig. 7.)—This well is sunk in the lias formation, and pierces the following strata:—3 ft. made ground, 13 ft. 9 in. rubble stone, 6 ft. stone, 135 ft. 3 in. blue cluncle, 14 ft. 3 in. hard stone, 18 ft. 6 in. clay stone, 9 in. stone, 35 ft. 6 in. clay stone, 3 ft. stone, 23 ft. 3 in. clay stone. The well is steined with brickwork and iron cylinders in the following order:—For 16 ft. 9 in. in depth the well is 7 ft. 6 in. diameter lined with brickwork; at this depth two cast-iron cylinders, 5 ft. 6 in. diameter, are introduced, which are again succeeded by 9 in. brick steining, commencing at 5 ft. 6 in. internal diameter, and widening out to 7 ft. 6 in. diameter; the floor of the well formed in brickwork at 120 ft. in depth from the surface; in this floor the boring commences, and for the first 31 ft. it is lined with 14 in. pipes, which rise into the well 5 ft. above the floor. The remaining portion of the bore-hole, 89 ft., is 9 in. diameter.

Southampton.—(Plate 6.)—The well sunk on Southampton Common, with the intention of supplying water to the town, turned out to be a failure as regards procuring a supply of water, although it is a fine example of the art and skill of the well sinker. The well is sunk to the depth of 563 ft., and bored a further distance of 754 ft., making a total depth of 1317 ft. The upper portion of this well was executed in brickwork. At 10 ft. from the surface iron cylinders, 13 ft. diameter, were introduced, which were continued to the depth of 62 ft. from the surface, when the contractor failed in his work, which at this depth was 2 ft. out of the perpendicular. The work was now undertaken by Mr. Thomas Docwra, a gentleman who has had great experience in well sinking; but, before the fresh work could be proceeded with, it was necessary to secure and strengthen the upper cylinders, which, owing to the violent measures used to drive them, were cracked and broken in all directions. This strengthening was accomplished by the introduction of cast-iron curbs, suspended from the flanges of the cylinders; and when the work had been in this manner thoroughly secured, the new work was proceeded with; three built up cylinders 8 ft. 6 in. diameter were introduced within the 13 ft. cylinders, and extending about 3 ft. below them; then steining with brickwork was commenced, which gradually widened out until at the depth of 72 ft. it was 14 ft. diameter; steining was continued to the depth of 164 ft., and was lined within with iron cylinders, backed with concrete; at this depth (164 ft.) a set-off was made and the well was continued in 14 in. brick steining, having a diameter of 11 ft. 6 in., until the well had reached the depth of 214 ft., when another set-off was made and the well was continued in 14 in. brickwork, 10 ft. diameter, to the depth of 267 ft. from the surface; at this depth another set-off was made, and the well was continued in 9 in. brickwork, 8 ft. 6 in. diameter, until the well had reached the depth of 302 ft.; when at about this depth it was ascertained that the work would have to be continued through a bed of running sand, and special means were adopted to secure the work above. These means consisted of the introduction of an iron curb, and the work was suspended by iron rods to another curb at the set-off, 267 ft. from the surface; this latter curb, in its turn, was suspended by means of strong chains to the bottom of the cast-iron cylinders at 163 ft. from the surface. When the work had been thus secured, a single cylinder of cast-iron 8 ft. diameter, extending 2 ft. within the 9 in. brick steining, was introduced, and below this 4½ in. brick steining, lined with cast-iron cylinders 7 ft. diameter, was executed, the space between the brickwork and the cylinders being filled with puddle. A sluice was made in one of the cylinders, which could be opened to admit water at pleasure; at 322 ft. from the surface the use of iron cylinders was discontinued, and the work was carried forward in 9 in. steining, the well being 6 ft. 9 in. diameter, to the depth of 467 ft., at which point the steining was terminated upon 18 in. footings of brickwork bedded in the chalk. The remaining portion of sinking was executed in the chalk, without the use of steining, until, at the depth of 563 ft., a trial bore 7 in. diameter was made to an additional depth of 754 ft., when owing to the great expenses incurred, and the probability that if water was to be reached at all it would be salt and unfit for the purposes required, this enterprise was abandoned.

Southend Waterworks.—(Plate 5, Fig. 8.)—This well is an ordinary steined well 416 ft. deep; for 201 ft. deep it is 6 ft. diameter, and steined with 9 in. brickwork, the remaining 215 ft. is 4 ft. 6 in. diameter, and steined with 4½ in. brickwork. The well is sunk through the following strata:—3 ft. surface soil, 30 ft. yellow clay, 383 ft. of blue clay; at this depth a bed of running mud was encountered, and the water rose to within 100 ft. of the surface.

Wormley, Herts.—(Plate 5, Fig. 9.)—This well is 135 ft. 6 in. deep, and is sunk in the chalk. The water rises to within 61 ft. 8 in. of the surface. For 38 ft. the well is 4 ft. diameter, at which point it commences to widen, until at 50 ft. it is 6 ft. diameter, at which size it is continued until 70 ft. is reached; the whole of the work is steined with 4½ in. brickwork; for 15 ft. deeper the well is 3 ft. 9 in. diameter, the upper portion of which is steined with wooden curbs, the well terminates in a bore 6 in. diameter, and 50 ft. 6 in. deep. In executing this well the following strata were pierced:—1 ft. surface earth, 9 ft. loam, 10 ft. yellow clay, 12 ft. blue clay, 6 ft. brown sand, 14 ft. white sand with pebbles, 20 ft. brown sand with water, which was succeeded by the chalk.

ABSORBING WELLS.

Wells and borings have been occasionally made for absorbing waste water, which is conveyed into the absorbent strata, and which, being disseminated over a large district, finally makes its escape at the points of natural overflow. It has been observed that, in making use of wells for this work, any ordinary well will absorb a quantity of water equal to its yield, provided that the water is free from matter likely to choke the pores of the absorbent strata. Thus it has been proved that if the natural water level in a well is 20 ft. from the surface, and by reducing the water level to 30 ft. from the surface, the well will yield 100 gallons per minute; by raising the water level 10 ft. from the original level, or within 10 ft. of the surface of the ground, the well will absorb water at the rate of 100 gallons per minute. Wells of this description have been executed in many places purposely to get rid of surplus water; thus an extensive plain near Marseilles, which was originally a morass, had been effectually drained in this way. In this country it has often been found that, to carry out agricultural drainage, water may sometimes be got rid of by simply boring through the upper crust of clay or other impervious strata into the porous strata below. Absorbing wells should not, under any circumstances, be used except to take away pure water; as the effect of discharging impure water into these wells would be to contaminate the wells of the neighbourhood used for procuring supplies of water. The practice of making cesspools absorbing wells is a most pernicious one, and cannot be too strongly condemned, as not only may it spoil the water of any wells in the immediate neighbourhood, but when the strata are very porous it may pollute wells and springs more remote.

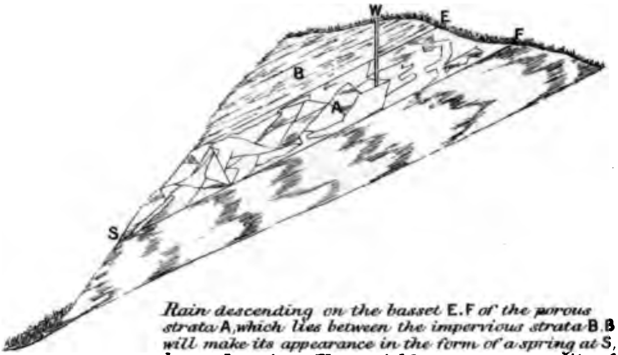
Necessity of Drainage.

Whenever an artificial supply of water is conveyed into a town which previously has been supplied from wells, it may be found that without a proper system of drainage or sewerage to convey away the surplus water, the healthiness of the place, instead of being improved by an abundant supply of pure water, may be injured, as the constant pumping from the wells of a district tend very naturally to promote the dryness and healthiness of the soil, and when the pumping is discontinued, dampness with all its evils are brought into play, which are augmented by the additional supply of water.

PLATE . 1.

Fig . 7

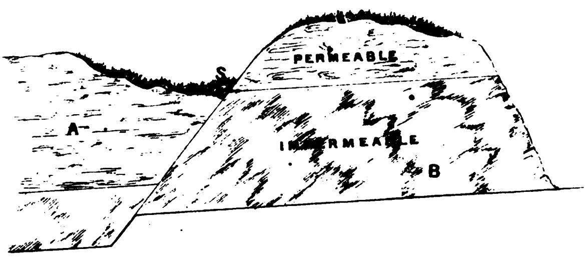
Shewing the causes which sometimes conduce to a limited supply of water in Artesian Wells.



Rain descending on the basset E.F *of the porous strata* A, *which lies between the impervious strata* B.B *will make its appearance in the form of a spring at* S, *but such spring will not yield any great quantity of water, as the area* E.F *which receives the rain fall is limited in its extent. - A well sunk at* W *in strata of the above description would not be likely to furnish a large supply if any water.*

Fig . 8

Shewing the effect of a fault



A spring will in all probability make its appearance at the point S *and such spring will in all probability be large, as the whole body of water flowing through the porous strata* A *is intercepted by being thrown against the impermeable strata* B.

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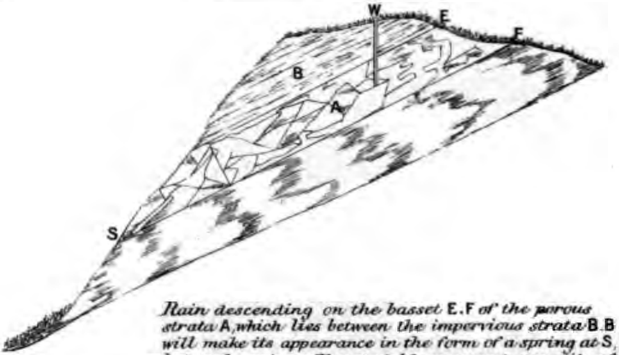
Fig. 7

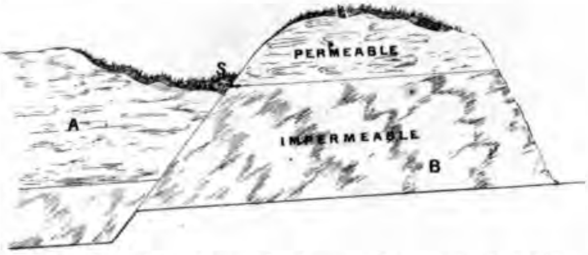
Shewing the causes which sometimes conduce to a limited supply of water in Artesian Wells.



Rain descending on the basset E.F *of the porous strata* A, *which lies between the impervious strata* B.B *will make its appearance in the form of a spring at* S, *but such spring will not yield any great quantity of water, as the area* E.F *which receives the rain fall is limited in its extent. - A well sunk at* W *in strata of the above description would not be likely to furnish a large supply if any water.*

Fig. 8

Shewing the effect of a fault



A spring will in all probability make its appearance at the point S *and such spring will in all probability be large, as the whole body of water flowing through the porous strata* A *is intercepted by being thrown against the impermeable strata* B.

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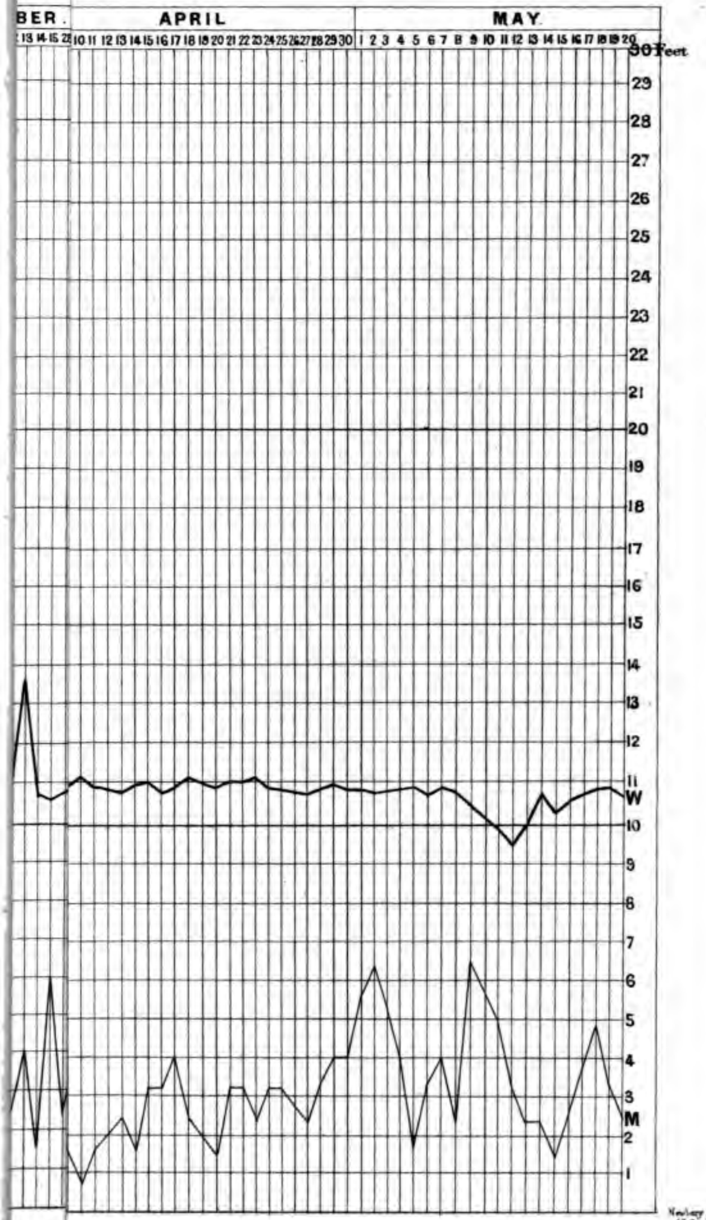
PLATE. 2



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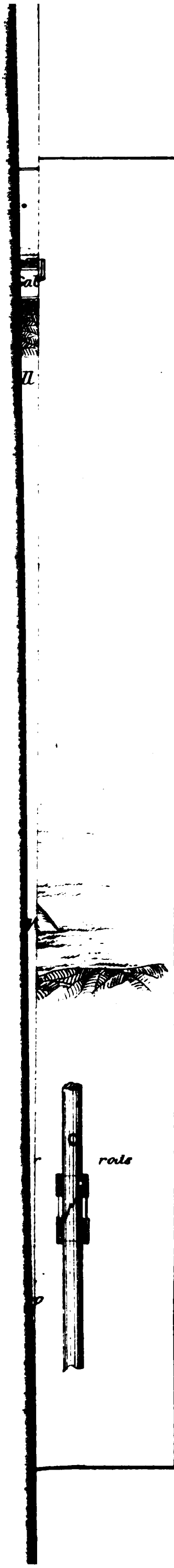


BORING TOOLS.

Slide Joint of Œynhausen

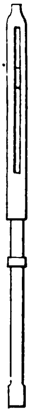
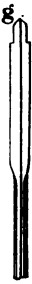


Fig. 4.

Chisels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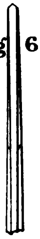
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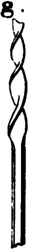
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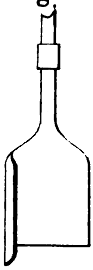
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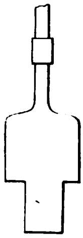
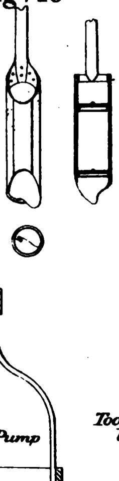


Fig. 9

Augurs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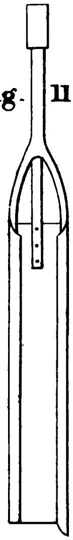
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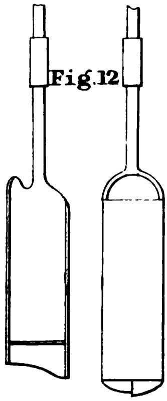
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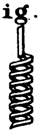


Fig. 13

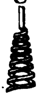
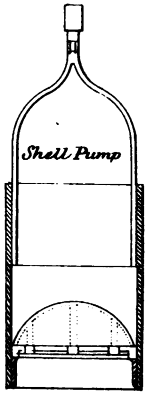


Fig. 14


Shell Pump

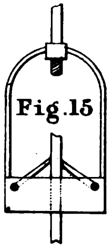
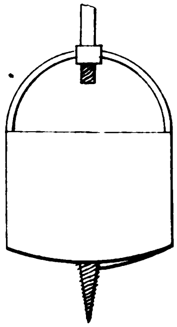

Tool for raising broken rods

Fig. 15


Miser

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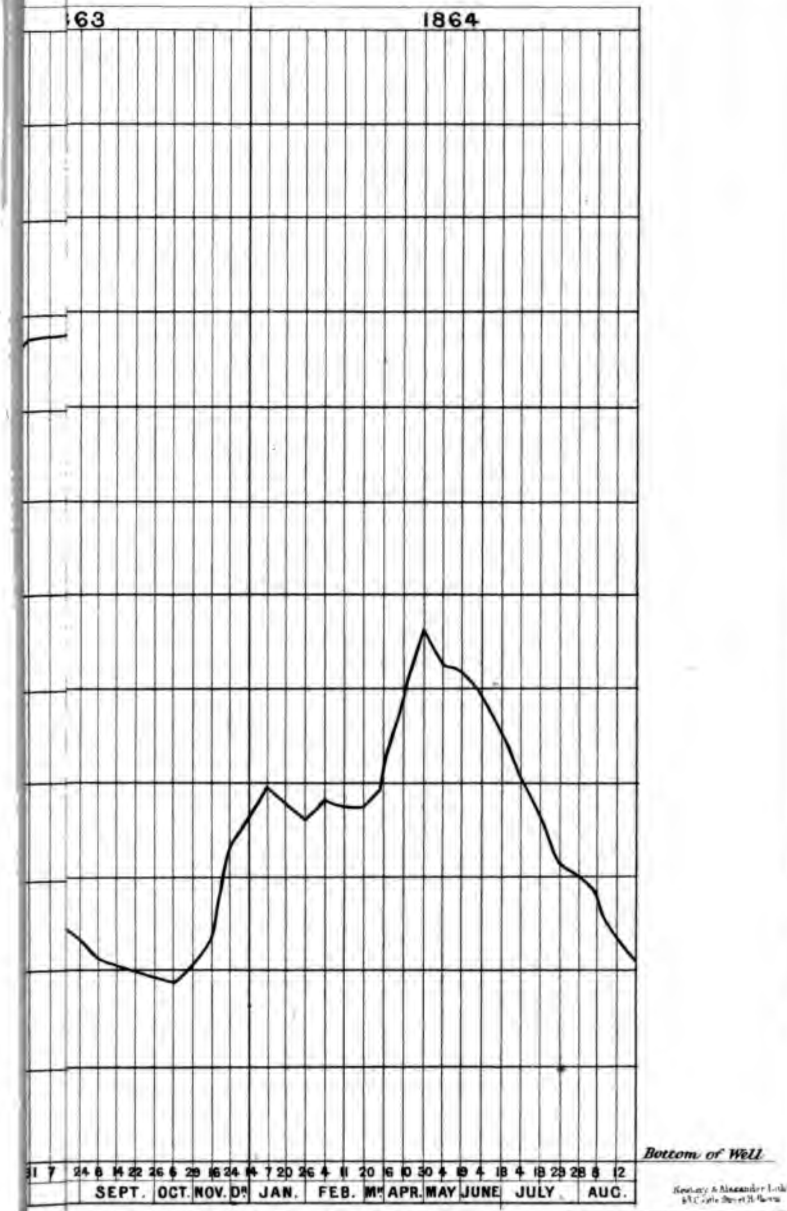

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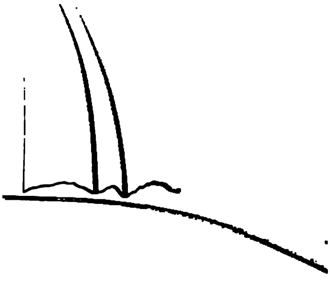
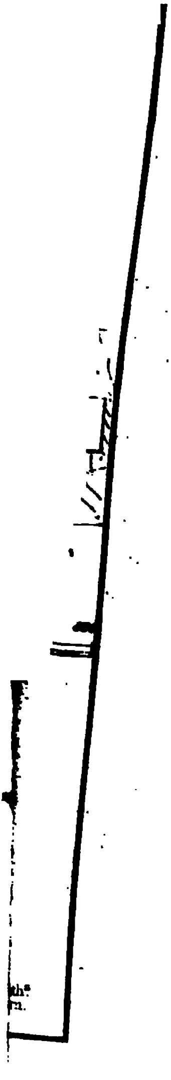
PLATE 6.

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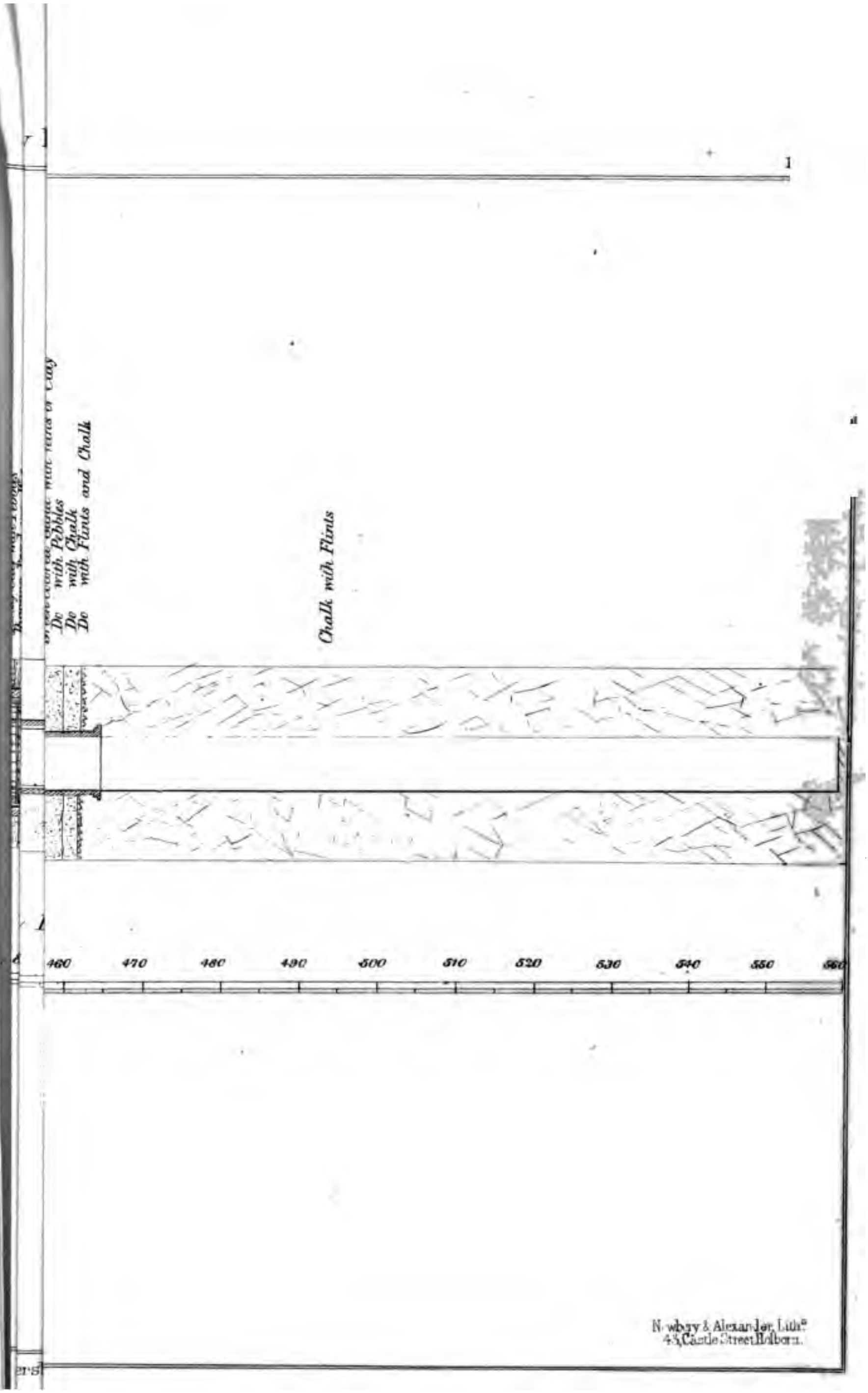

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